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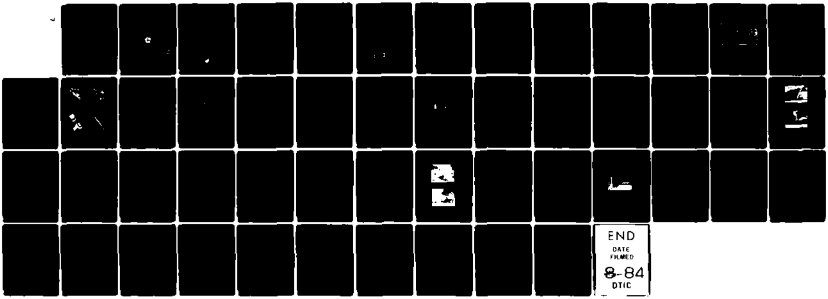

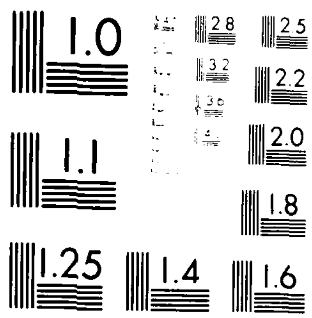

MICROCOPY RESOLUTION TEST CHART

REPORT NO: CG-D-11-84

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EVALUATION OF AQUEOUS FILM FORMING FOAMS (AFFF) ON DECK FIRES

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October 1983

Final Report

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15. Supplementary Notes

Aqueous film forming foam (AFFF) concentrates were tested in full-scale deck fires at the U.S. Coast Guard Fire and Safety Test Detachment in Mobile, Alabama. The testing was conducted on the after tank deck of the Tank Vessel A.E. WATTS. It simulated a spill fire with obstructions on the after flight deck of a Coast Guard cutter. The spill fires were conducted using marine diesel as the test fuel.

The purpose of the testing was to evaluate the firefighting effectiveness of different AFFF concentrates and to determine whether 1% or 3% AFFF concentrates could be used to replace the 6% Military Specification AFFF concentrate used on board Coast Guard cutters. This replacement could reduce the weight and space required for AFFF storage or increase the overall time of firefighting effectiveness. The AFFF's tested were 3% and 6% AFFF concentrates meeting Military Specification MIL-F-24385, two commercial 3% AFFF concentrates, two polar solvent resistant 3% AFFF concentrates, and a 1% commercial AFFF concentrate. A secondary objective was to evaluate the firefighting effectiveness of the four nozzles used aboard Coast Guard cutters when using AFFF.

The tests demonstrated that the 3% AFFF concentrates were as effective as the 6% Military Specification AFFF concentrate in controlling and extinguishing deck fires. The test results also indicated that the 3% AFFF concentrates compared equally to the 6% Military Specification AFFF concentrate in sealing around hot metal surfaces and in burnback resistance. The 1% AFFF concentrate had control and extinguishment times comparable to those of the 6% AFFF Military Specification concentrate, but it was the least acceptable AFFF because of its poor burnback resistance. These test results are based on accurate AFFF proportioning. If the accuracy of the proportioners used is questionable, then sensivity testing should be conducted.

The Coast Guard All Purpose (CGAP) nozzle and the Twin Agent Unit (TAU) nozzle had the longest control and extinguishment times while the Mechanical Foam Nozzle (MFN) and the Select-O-Flow (SFL) nozzle had the shortest control and extinguishment times. The SFL nozzle with its multiple control modes was the most versatile and overall effective nozzle.

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METRIC CONVERSION FACTORS

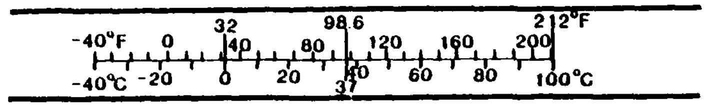
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286. Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10:286

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Acknowledgements

The U.S. Coast Guard appreciates the assistance of National Foam System, Inc., Ansul Fire Protection, 3M-Fire Protection Systems, Elkhart Brass Manufacturing Company, Inc., and Akron Brass Company in providing materials and equipment used during the testing. The willing cooperation and participation of these companies led to the successful accomplishment of this test program.

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1.0 INTRODUCTION

Aqueous film forming foam (AFFF) has gained widespread recognition in the fire service community as being an effective fire fighting foam for use on liquid spill fires and petroleum storage tank fires. This recognition is noted by the fact that AFFF is used by the Navy for shipboard firefighting and by the U.S. Air Force for crash rescue vehicles at its airfields. Fire fighting brigades of large oil refineries are also adopting AFFF for use. Due to its effectiveness and widespread use, the National Fire Protection Association has developed a National Fire Code of recommended practices for the use of AFFF.

Six percent AFFF meeting the requirements of MIL-F-24385 Type 6 is the only firefighting foam concentrate authorized for use on Coast Guard cutters and boats. The specification for 6% concentrate requires that 6% of each gallon of AFFF solution mixed is AFFF concentrate. Currently 3% and 1% AFFF concentrates are also commercially available. The 3% AFFF would require that 3% of each gallon of AFFF solution mixed is AFFF concentrate whereas a 1% AFF concentrate would require that 1% of each gallon of AFFF solution mixed is AFFF concentrate.

2.0 OBJECTIVES

The purpose of this testing was to evaluate the firefighting effectiveness of different AFFF concentrates to determine whether 1% or 3% AFFF concentrates could be used to replace the 6% Military Specification AFFF concentrate used on board Coast Guard cutters.[1] Such a replacement could reduce the weight and space required for AFFF storage aboard Coast Guard cutters by as much as 50% for 3% AFFF and 83% for 1% AFFF. The foams tested were 3% and 6% AFFF concentrates meeting Military Specification MIL-F-24385, two commercial 3% AFFF concentrates, two polar solvent resistant 3% AFFF concentrates, and a 1% commercial AFFF concentrate. All the foams tested are advertised for use on hydrocarbon (Class B) fires. Two of the foams are also designed for use on polar solvent (e.g. alcohol) type fires. The specific objectives were:

(1) To evaluate the firefighting effectiveness of different AFFF concentrates on deck fires.

(2) To evaluate the AFFF's ability to resist breakdown around hot metal obstructions.

(3) To evaluate the AFFF's foam blanket stability over an extended period of time.

(4) To evaluate and compare the above mentioned characteristics for commercial AFFF and AFFF meeting Military Specification MIL-F-24385C.

A secondary objective was to evaluate the firefighting effectiveness of nozzles on Coast Guard cutters while using AFFF. The AFFF used in this testing was to be either 6% AFFF or whichever concentrate proved equivalent to it.

The specific objectives of the nozzles evaluation were:

(1) To evaluate and compare the firefighting effectiveness of nozzles used on Coast Guard cutters when using AFFF.

(2) To evaluate and compare the foam characteristics produced by the nozzles.

3.0 BACKGROUND

3.1 Aqueous Film Forming Foam (AFFF)

AFFF is a combination of fluorocarbon surfactants and synthetic foaming agents which spread out across the surface of a liquid which is on fire to provide a rapid "knock-down" of the flames.[2] The new dimension in this foam is its aqueous film. This film is a thin layer of foam solution that rapidly spreads across the hydrocarbon fuel while extinguishing the flames as it spreads (figure 1). The aqueous film is produced by the action of the fluorocarbon surfactant reducing the surface tension of the foam solution to a point where the solution can actually be supported by the surface tension of the hydrocarbon fuel. The effectiveness and durability of the aqueous film is directly influenced by the surface tension of the hydrocarbon fuel. For example, AFFF is more effective on fuels having higher surface tension such as diesel oil, jet fuels and kerosene. It is less effective on fuels having lower surface tension such as hexane and high octane gasolines. It is the rapid drainage of the foam solution from the foam bubble which produces optimum filming for rapid fire extinguishment. There is concern that this rapid drainage results in short-term sealability and limited burnback resistance.

AFFF's have also been developed to combat polar solvent (water soluble) flammable liquids. This type of AFFF forms a cohesive polymeric film on the fuel surface of the polar solvent.[3] This polymeric layer protects the foam and its aqueous film from the chemical and physical breakdown action of the polar solvent. If the protective layer of polymeric film is broken by agitation, more polymeric film is produced to fill the break. When polar solvent resistant AFFF's are used on hydrocarbon fires, they extinguish the fire in the same manner as normal AFFF. Although polar solvent resistant foams may be used on hydrocarbon fires, historically they have not been as effective as normal protein or fluoroprotein foams. The new polar solvent resistant AFFF's have been specially formulated to be equally effective on hydrocarbon fires.

3.2 Extinguishment by AFFF

AFFF extinguishes a fire in three ways:

(1) It smothers the fire by using its aqueous film to prevent air from mixing with the flammable vapors.

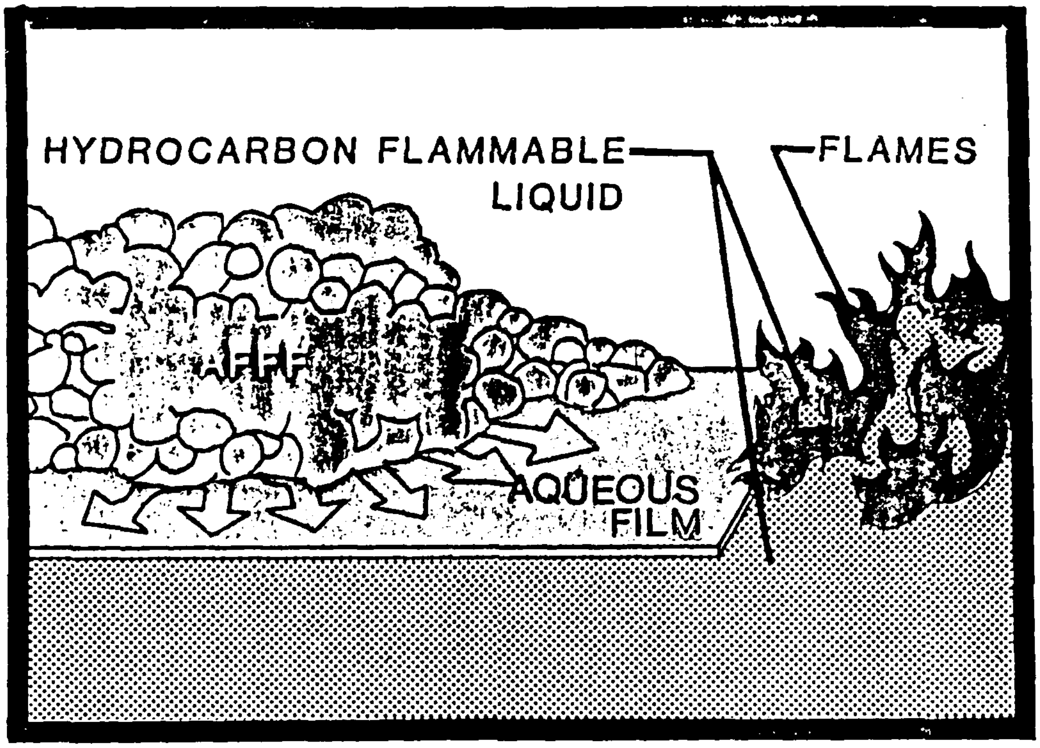


FIGURE 1
HOW AFFF WORKS

(2) It suppresses flammable vapors and prevents their release.

(3) It cools the fuel and adjacent metal surfaces.

The aqueous film, which produces the rapid "knockdown" of the fire, appears to be produced at the sacrifice of the foam blanket's cooling ability and its burnback resistance. This occurs as the aqueous film drains from the foam to knockdown the flames, for as the film is disrupted it regenerates itself at the foam's expense.

3.3 Codes and Specifications for Commercial Vessels

It has been the position of the Coast Guard that the rapid fire knockdown ability of AFFF is indicative of only a portion of fire fighting requirements. Title 46 Code of Federal Regulation, Part 34.05, requires the installation of deck foam systems aboard tankers, and that all such systems are Coast Guard approved. Coast Guard approval requires that the foam successfully meet the fire test requirements of Federal Specification 0-F-555C. These requirements address the firefighting effectiveness, sealability, and burnback resistance.

0-F-555C is a small-scale 100 square feet (9.3 sq m) fire test considered to be representative of some of the conditions encountered in full-scale tanker fires. It simulates:

1. The ability of the foam to resist breakdown when propelled from a foam monitor through a curtain of flame on to a metal backboard, then flowing down the hot metal and covering the surface of the burning fuel. This is in contrast to many industrial applications where the foam is spread gently from tank-side nozzles positioned at the liquid level height, resulting in a minimum exposure of the foam to flames and hot steel; or where foams are injected into the bottom of a tank and then float up through the fuel to its surface.

2. The ability of the foam blanket to resist breakdown over a period of time, thus preventing re-exposure of the fuel to sources of ignition. This is representative of tanker fire conditions where given the certain time needed for fire detection, system activation and response, a large segment of the ship may become involved in flames. If the fire is progressively fought from aft to forward from foam station to foam station, the length of time required for the foam blanket to remain effective in covering and sealing the fuel is considered to be a minimum of 20 minutes.

3. The ability of the foam to contain reignited openings in the foam blanket, and thus prevent the entire hazard area from reflashing. This is determined by opening a measured area in the foam blanket, igniting it, and determining the breakdown rate of the surrounding foam blanket.

At the time Federal Specification 0-F-555C was developed as a small-scale fire test and correlated to full-scale tanker-type fires, the only commercially available foam was 6% protein foam concentrate. Later, 3% protein foam concentrate, flouroprotein synthetic foams, and AFFF were developed. A modified Coast Guard version of 0-F-555C was not adopted since it was the Coast Guard's position that the hazard conditions addressed by 0-F-555C remained unchanged and any newer foams should address these same

hazardous conditions.

3.4 AFFF On Coast Guard Cutters

Aqueous film forming foam plays an important role in the overall fire protection on Coast Guard cutters.

a. Engine room protection is proved by a Twin Agent Unit (TAU). This unit provides AFFF solution and PKP (dry powder) through twin hoses and a dual nozzle setup such that an operator can apply either foam and or dry chemical as needed.

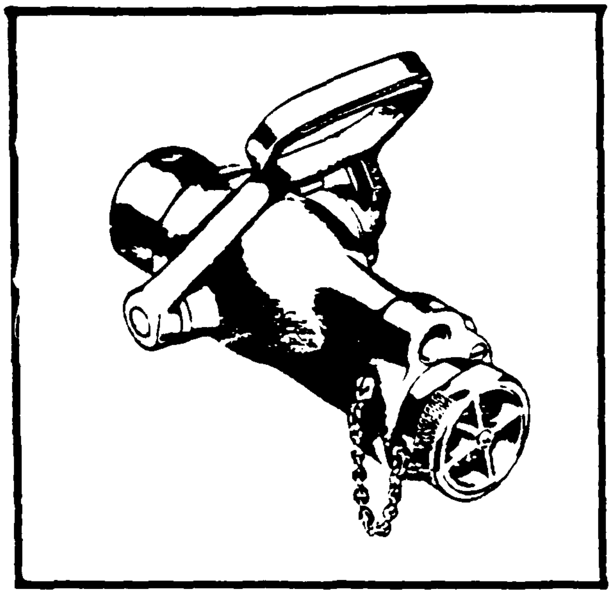
b. Helicopter flight deck protection is provided from two AFFF hose stations with SFL type variable pattern foam nozzles. The foam solution for these stations is usually provided from an installed proportioner system.

c. All cutters carry Type 6 AFFF in pails [5 gallons (18.9 liters) each], portable inline eductor type proportioners, and mechanical foam nozzles for protection of machinery spaces, and flight decks.

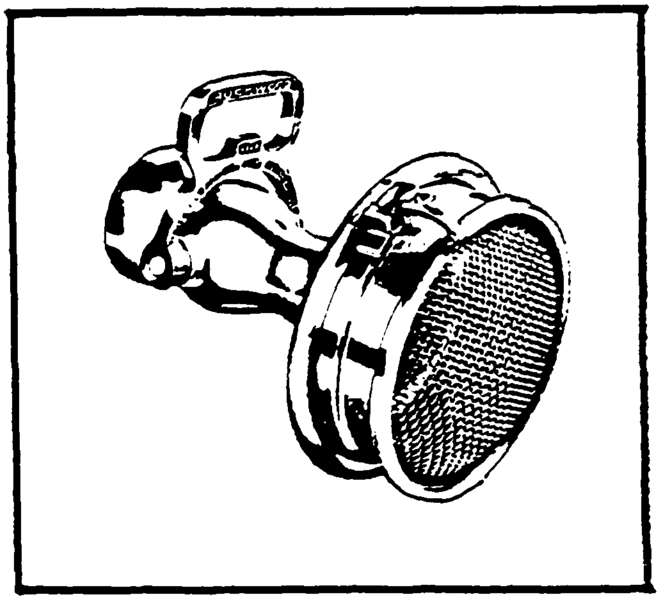
d. The only foam concentrate currently authorized by the Commandant for use aboard Coast Guard cutters and boats is Military Specification MIL-F-24385C Type 6. When properly proportioned, 6 parts of AFFF concentrate plus 94 parts water equal 100 parts of unexpanded foam solution.

3.5 Nozzles Used on Coast Guard Cutters

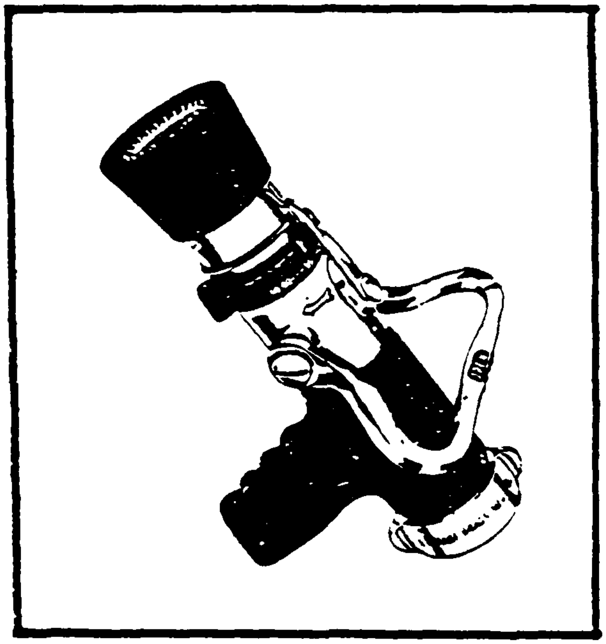
Only four nozzles are authorized for use on Coast Guard cutters. These authorized nozzles include the 1 1/2-inch Coast Guard All Purpose (CGAP) nozzle, the 1 1/2-inch Mechanical Foam Nozzle (MFN), the 1 1/2-inch Select-O-Flow (SFL) nozzle, and the Twin Agent Unit (TAU) nozzle (figure 2). Each of these nozzles can use an AFFF solution to attack a fire, but basically only two of the nozzles are designed as foam application devices. The firefighting effectiveness thus varies because of different nozzle design and depending on how and where the nozzle is being used. For example, the Twin Agent Unit nozzle is an aerating type nozzle with the aeration being external to the nozzle as the solution passes through an expanded metal screen. It is designed for close-up fire situations such as in a bilge or engine fire. It, therefore, provides a wide fog pattern but does not have a great reach against a deck fire. The 1 1/2-inch SFL nozzle because of its adjustable fog pattern and straight stream patterns would be capable of both closeup and long-range type fire fighting. The spray pattern generated and the teeth in the face of the nozzle aerates the foam to some degree thereby increasing its overall effectiveness. The 1 1/2-inch Mechanical Foam Nozzle is an aerating type nozzle with eration occurring inside the nozzle. It has good range capabilities but has no adjustment mechanism for a fog pattern for close firefighting situations. In this type situation its foam discharge would have to be banked off a wall or obstruction. Close-up firefighting could be hazardous to its operator. The 1 1/2-inch Coast Guard All Purpose nozzle has both a straight stream and fog pattern setting but its design fails to aerate the AFFF sufficiently to create a thick frothy foam blanket.



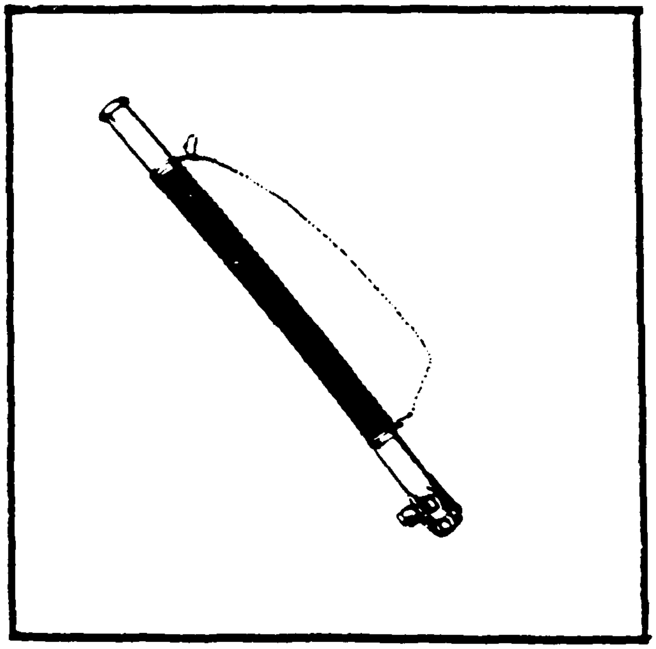
COAST GUARD ALL PURPOSE NOZZLE



TWIN AGENT UNIT NOZZLE



SFL NOZZLE



MECHANICAL FOAM NOZZLE

FIGURE 2
NOZZLES USED ON COAST GUARD CUTTERS

4.0 APPROACH

All testing was conducted at the U.S. Coast Guard Fire and Safety Test Detachment in Mobile, Alabama. Full-scale fire tests, burnback tests, sealability tests, and foam quality tests were conducted on the after tank deck of the Tank Vessel A. E. WATTS at Little Sand Island (figure 3). A premix foam tank and a foam pump were used in all the full-scale fire testing. The vessel was fitted with the necessary fire containment barriers, fire mains, and instrumentation. Three pretest fires were conducted to determine the application rate which would provide optimum control and extinguishing times for comparison and evaluation of the AFFF concentrates and of the different nozzles. All final nozzle adjustments were worked out in the pretest fires. The different AFFF's were evaluated with an SFL nozzle on an oscillating mount while the four nozzle described in Section 3.5 were evaluated under manual operating conditions.

The primary independent variables for the AFFF evaluation were the fire type, the extinguishing mode, the AFFF concentrates and the different nozzles (Figure 4). Test parameters held constant were: number of tests per set-up, preburn time, fuel type, ignition source, and fire fighting technique. The principal dependent variables measured were control times, extinguishing times, sealability and burnback resistance.

4.1 Fire Scenario

The test series was intended to simulate a fire surrounding a disabled helicopter on the aft deck of a Coast Guard cutter. A worst case fire scenario describing this situation is as follows: During the final refueling of a helicopter on the deck of a Coast Guard cutter, the landing carriage collapses and the fuel tank ruptures spilling fuel onto the cutter's deck. The fuel then ignites by an ignition source created by the helicopter's collapse. The fire spreads rapidly across the deck and is fueled by the hose line which was refueling the helicopter. A spill fire with obstructions has occurred. Wind conditions and a delay in attacking the fire add to the difficulty of its extinguishment.

4.2 Limitations

An inherent problem in any full-scale testing is the difficulty in duplicating all the variables which affect the results. This in turn leads to difficulty in the repeatability of test results and a potential loss of test credibility. In this test series, each test was conducted three times to provide confidence and credibility in the results.

The test schedule was designed to provide consistent results in the presence of experimental testing which often produces bias or random errors. Blocking and randomization were used to reduce or eliminate bias errors attributed to different AFFF concentrates, nozzles, and environmental factors. The test schedule in Table 1 employed the above techniques for the testing sequence of the AFFF concentrates and the nozzles.

The use of the oscillating nozzle reduced any bias error associated with different operators. Additionally, it insured that each of the foam concentrates was applied in the same manner and that the same quantity of foam

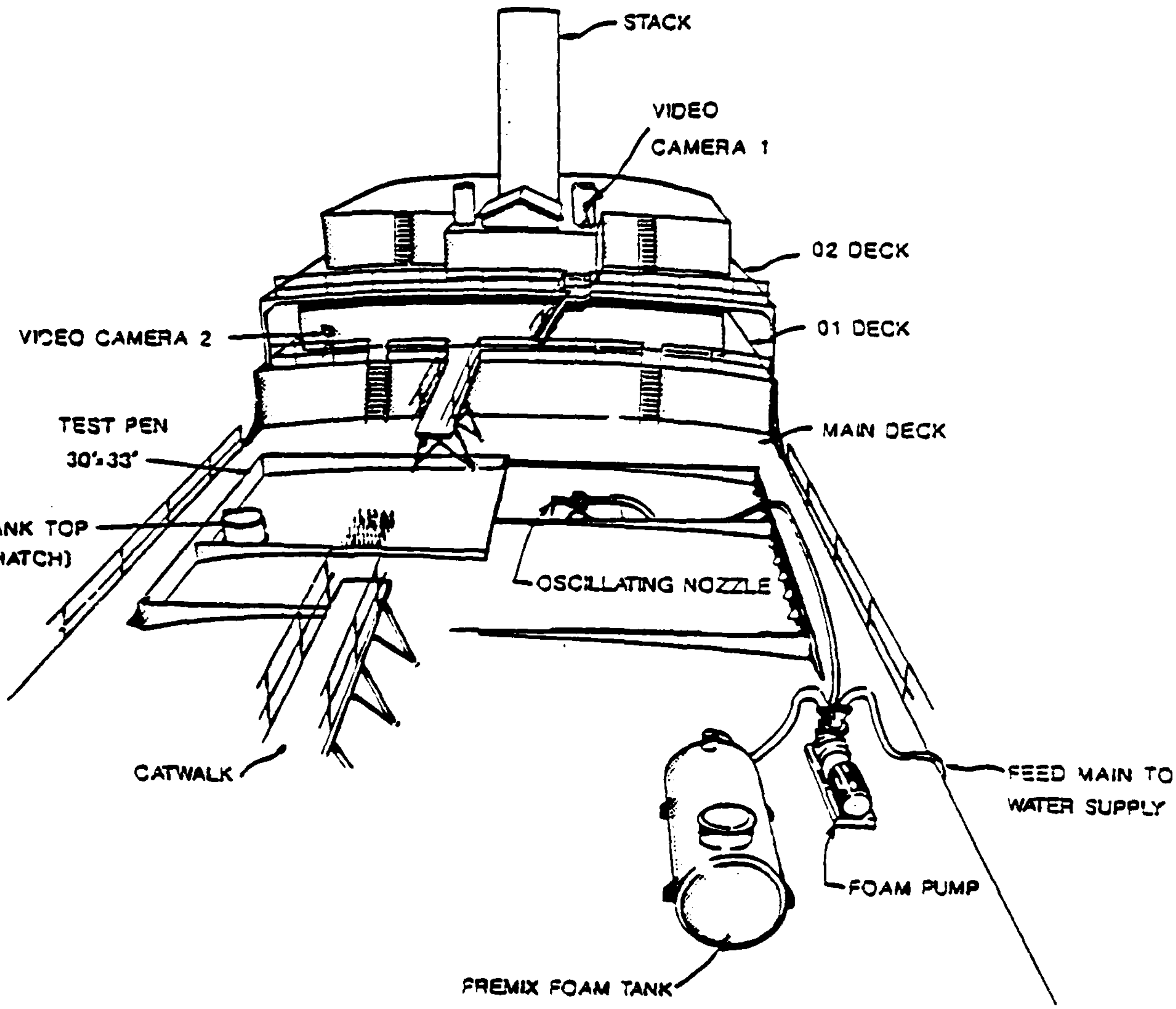


FIGURE 3
TEST AREA ON TANK VESSEL A.E. WATTS

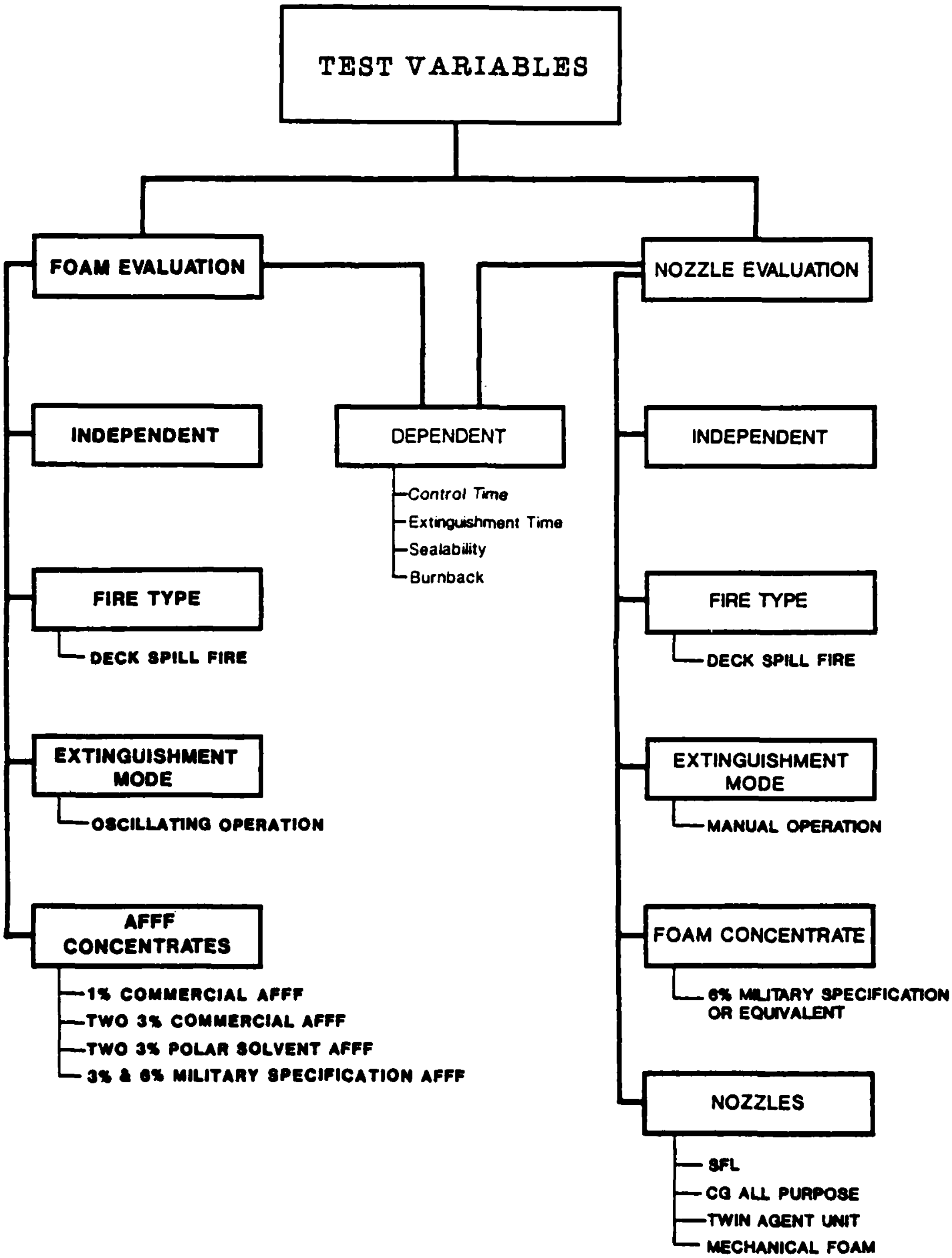


FIGURE 4

DIAGRAM OF TEST VARIABLES

TABLE 1
TEST SCHEDULE

OSCILLATING OPERATION		MANUAL OPERATION
Pretest#/Nozzle-AFFF	Test#/Nozzle-AFFF	Test#/Nozzle-AFFF
1-A	1-A	22-H
2-A	2-B	23-I
3-A	3-C	24-J
	4-C	25-K
	5-A	26-H
	6-B	27-I
	7-B	28-J
	8-C	29-K
	9-A	30-H
	10-D	31-I
	11-E	32-J
	12-F	33-K
	13-F	
	14-D	
	15-E	
	16-E	
	17-F	
	18-D	
	19-G	
	20-G	
	21-G	

Legend: (Nozzle, AFFF Concentrate, Foam Manufacturer)

A = SFL	6% Military Specification	(Ansulite)	Ansul Fire Protection
B = SFL	3% Commercial	(Aer-O-Water)	National Foam System, Inc.
C = SFL	3% Military Specification	(Ansulite)	Ansul Fire Protection
D = SFL	3% Polar Solvent Resistant	(National Universal)	National Foam System, Inc.
E = SFL	3% Commercial	(Light Water)	3M Fire Protection
F = SFL	1% Commercial	(Ansulite)	Ansul Fire Protection
G = SFL	3% Polar Solvent Resistant	(Alcohol Type Concentrate)	3M Fire Protection
H = TAU	3% Military Specification	(Ansulite)	Ansul Fire Protection
I = CGAP	3% Military Specification	(Ansulite)	Ansul Fire Protection
J = SFL	3% Military Specification	(Ansulite)	Ansul Fire Protection
K = MFN	3% Military Specification	(Ansulite)	Ansul Fire Protection

was delivered inside the test pen. The nozzle pattern was preadjusted to insure no waste. Longer control and extinguishment times might be expected because of the passive extinguishment method of the oscillating nozzle, but the most valid comparison of foam effectiveness was made with a reproducible firefighting technique.

Only one operator was used in the nozzle testing in order to eliminate different extinguishing techniques or methods attributed to different human operators. Randomization of the different nozzles reduced any additive learning effects by not allowing the same nozzle to be used consecutively. The active extinguishing method of the operator provided a realistic evaluation of the different nozzle's effectiveness during manual operation.

5.0 PROCEDURES

The testing was conducted in a test pen fitted with the instrumentation necessary to record temperatures, wind speed, wind direction, test time, and heat fluxes. Color videotapes and 35mm cameras were used to document each test.

5.1 Test Pen And Fuel

A series of steel coamings on the after main deck of the Tank Vessel A.E. WATTS was used as the test pen. The test pen contained approximately 1000 square feet (92.9 sq m) and was 33 feet (10.1m) long by 30 feet (9.1m) wide (figure 5). Several obstructions were included inside the test pen. Normally, the fire situation during the crash of a helicopter refueling on a Coast Guard cutter would involve JP5. Its high cost and the difficulty of securing and transporting it to the test site necessitated the use of a substitute fuel. Marine diesel was used as the test fuel since it is less expensive, more available, and has similar flammability characteristics[5] (Table 2).

The test pen was filled with water to a depth of two to four inches (5.1 to 10.2 cm) below the top of the coaming. The test fuel was floated on the water's surface, its depth ranging from one to two inches (2.5 to 5.0 cm). The test fuel covered the entire test pen except for an existing tank top and obstructions. Floating the fuel on the water surface served to protect the deck from the intense heat of the flames. Sections of the deck around the test pen required water applied to it during each test to keep the deck plates from buckling.

Since the more volatile fuel elements burned off and the fuel was diluted by the continued application of foam during each test, fresh fuel was added before each test to reproduce flame severity. Ten gallons of mineral spirits were spread over the fuel prior to each test to aid in ignition. Two firefighters used special propane torches to ignite the mineral spirits along three sides of the test pen. Flames normally engulfed the entire test pen in two and a half minutes. A one minute full involvement preburn was given for each test. Foam discharge was initiated at the foam pump at the conclusion of the one-minute preburn. At the conclusion of each test the water level in the test pen was raised so that the remaining AFFF could be skimmed off the fuel surface into an adjacent holding pen.

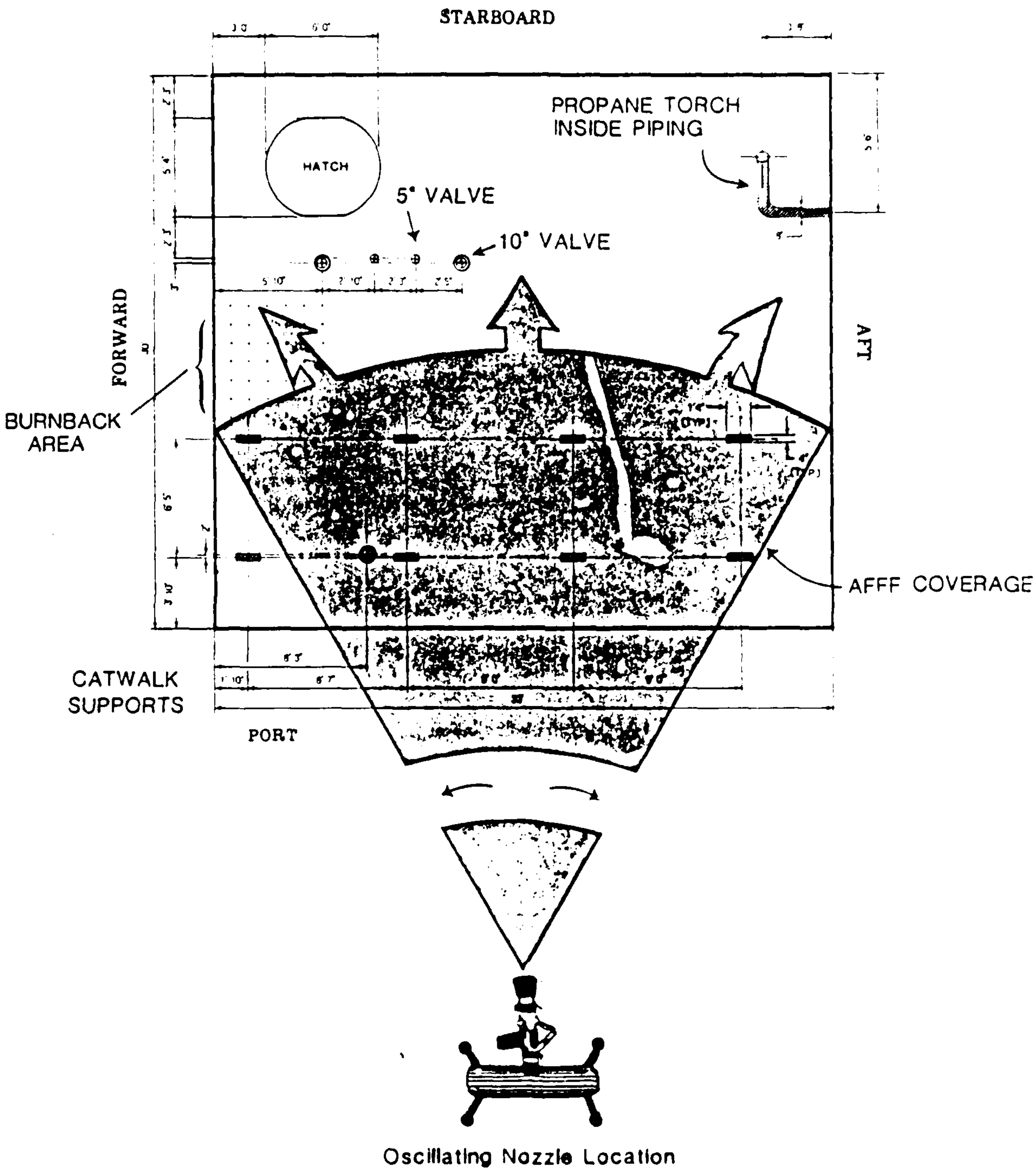


FIGURE 5

TEST PEN

TABLE 2
COMPARISON OF FUEL CHARACTERISTICS

	Marine Diesel	JP-5
Flash Point	125°F (51.7°C)	140°F (60°C)
Flammable Limits in Air	1.3% - 6.0%	0.6% - 4.6%
Ignition Temperature	490-545°F (254.4-285°C)	475°F (246°C)
NFPA Fire Hazard Classification	Red, 2	Red, 2
Availability	Delivered to test ship by barge	Hire a truck driver for pickup and delivery from out of state (three trips). Move LCM with storage tank back and forth to test ships (three trips)
Price	$1.05/gal	$1.25/gal

5.2 Fire Tests

A total of 36 fire tests were conducted, including three pretest fires to insure that the oscillating nozzle and the foam pump were functioning properly. Twenty-one fire tests were conducted to evaluate the seven AFFF concentrates while 12 fire tests were conducted to investigate the effectiveness of the four nozzles. Each of the seven AFFF concentrates and each of the nozzles was used in three separate fire tests.

5.3 Nozzle Operation

A non-aerating type nozzle on an oscillating base was used in the 21 fire tests fires to evaluate the different AFFF concentrates (Table 3). The SFL nozzle was used for the 21 tests. This nozzle is normally located on a Coast Guard cutter flight deck and would be the primary nozzle used in an after deck spill fire. The oscillating base was preadjusted to a fixed angle of elevation and arc of oscillation. Identical oscillation of the SFL nozzle was used in each test. This increased the repeatability of test results and served to eliminate errors associated with different attack patterns associated to human operators. The non-aerating nozzle was operated at a flow rate of 95 gallons per minute (360 lpm) and a nozzle pressure of 100 psi (685 kN/m^2) for the AFFF evaluation. This flow rate was determined from the three pretest fires.

The 12 nozzle fire tests were extinguished by a firefighter in a proximity suit. A different nozzle was used each time to insure that the operator's learning curve developed equally for each nozzle (Table 3). The four nozzles tested are listed in section 3.5. The nozzles were operated at flow rates from 60 to 45 gallons per minute (227 lpm to 170 lpm) and at an operating pressure of 100 psi (685 kN/m^2) Variable flow rates were used because a single rate was not common to each nozzle. This did permit a comparison of similar flow rates. The aggressive attack procedure of the operator made up for the difference in flow rates between the AFFF concentrate testing and the nozzle testing.

5.4 Foam Quality

For each fire test a foam sample was collected for qualitative testing. The samples were collected in accordance with National Fire Protection Association Standard No. (NFPA) 412[6], Appendix A-220. Foam expansion determination was determined according to NFPA 412, page 412-20, Appendix A-230, and foam drainage times were determined according to NFPA 412, Appendix A-240. The above methods are described in Appendix A.

5.5 Application Rate

A single application rate of 0.1 gallons per minute per square foot (4.1 liters per minute per square meter (lpmin/sqm)) was used with the oscillating nozzle to conduct the AFFF concentrate testing. A smaller application rate of 0.04 gallons per minute per square foot (1.6 lpmin/sqm) was tested with the oscillating nozzle on two pretest fires but the fires were neither controlled nor extinguished. A third pretest fire was successfully extinguished in 3 minutes and 20 seconds using the 0.1 gallons per minute per square foot (4.1 lpmin/sqm) rate, therefore it was used as the test rate. Previous small scale testing indicates that fires can be extinguished manually by smaller application rates when using an aggressive attack mode. The larger test application rate, however, provided a margin of safety to account for the

application rate selected is also used in Coast Guard approved AFFF systems for protecting helicopter decks on mobile offshore drilling rigs and is recommended by the National Fire Codes for the extinguishment of hydrocarbon spill fires.

Application rates used in testing the effectiveness of the four nozzles mentioned varied from .045 to 0.06 gallons per minute per square foot (1.8 to 2.4 lpmin/sqm). These rates are considered to be slightly above the minimum rate considered necessary for flame extinguishment.

TABLE 3
CONTROL MODES USED DURING TESTING

Control Mode	Number of Tests	Nozzle	AFFF Concentrate
Oscillating	3	SFL	1% Commercial (Ansulite)
Oscillating	3	SFL	3% Military Specification MIL-F-24385C (Ansulite)
Oscillating	3	SFL	6% Military Specification MIL-F-24385C (Ansulite)
Oscillating	3	SFL	3% Commercial (Light Water)
Oscillating	3	SFL	3% Commercial (Aer-O-Water)
Oscillating	3	SFL	3% Polar Solvent Resistant (Alcohol Type Concentrate)
Oscillating	3	SFL	3% Polar Solvent Resistant (National Universal)
Manual	3	1 1/2" SFL	3% Military Specification MIL-F-24385C (Ansulite)
Manual	3	1 1/2" CG All Purpose Nozzle	3% Military Specification MIL-F-24385C (Ansulite)
Manual	3	1 1/2" TAU	3% Military Specification MIL-F-24385C (Ansulite)
Manual	3	1 1/2" MFN	3% Military Specification MIL-F-24385C (Ansulite)

5.6 Foam Proportioning

A 500 gallon (1892.5 l) premix tank and pump were used to provide the foam solution used in each test. The foam proportioning concentration was checked by two methods. One method used is listed in NFPA 412, Appendix A-250. The second method is used by the Navy and also involves the use of a refractometer. The formula for this method is:

$$PC = \frac{RN - RS}{RC - RS \times 100}$$

where: proportioning concentration = PC
refractive index of foam solution at nozzle = RN
refractive index of saltwater = RS
refractive index of foam concentrate = RC

Before each test the tank was filled with seawater and a predetermined quantity of foam concentrate to form the desired foam solution concentration. A motor driven propeller was located inside the tank to thoroughly mix the foam concentrate and seawater. After each test, the tank was drained and flushed before the next AFFF soluton was mixed.

5.7 Control/Extinguishment

Control time was subjectively determined as the time from AFFF application until the point where the fire would be of no further danger to the vessel if eventual extinguishment were made. This was considered to be a point where flames cover no more than ten percent of the test pen area. Extinguishment time was the time from AFFF application until all visible flames in the test pen coamings was out. Control times provide more consistant results than extinguishment times in evaluating fire fighting effectiveness because extinguishment times constantly vary due to flickering fires which continue to burn around obstructions or in and around the corners and edges of a test pen.[7, 8]

5.8 Sealability Tests

Sealability is a measure of a foam's ability to maintain its seal around surfaces when subjected to high temperatures. Failure occurs if the foam retracts from the high temperature sources and the fuel ignites. After each test fire had been extinguished, a heated pipe apparatus and two propane torches were used to determine the sealability of the AFFF being tested. One propane torch was placed inside a section of pipe which was half-submerged in the test pen water, fuel, and foam (figure 5). The second propane torch was positioned approximately 6 inches (15.2 cm) above the surface of the heated pipe which corresponded to about 7 inches (17.7 cm) above the surface of the fuel. Both propane torches were energized one minute after the test fire was

fully extinguished. Flames were applied for 15 minutes. The purpose was to determine if the foam would break away from the hot metal and if fuel vapor in this area would subsequently ignite.

5.9 Burnback Tests

The burnback tests were designed to measure the resistance of the foam blanket on the fuel to burnback after the test fires had been extinguished. One minute after each test fire was extinguished a one-foot (0.3 m) diameter circular open pan was placed inside the designated burnback area of the test pen. It was positioned on a line near the center of the forward coaming and three feet (0.9 m) inside the pen. This area was marked off in one-foot (0.3 m) spacings by steel rods extending one foot (0.3 m) high above the fuel and foam (Figure 5). These rods provide a reference for estimating the burnback area. The foam was cleaned out of the one-foot (0.3 m) pan and 14 ounces (0.4 l) of mineral spirits were added inside the pan to assist the ignition of the fuel. The mineral spirits were ignited by a propane torch two minutes after the entire test pen had been extinguished. The fuel inside the one-foot (0.3 m) pan was allowed to burn for one minute and then the pan was removed (Figure 6). The flames were allowed to continue for 15 minutes or until they consumed their way outside the designed test area. During this time, the rate and time of the enlargement of the fire were recorded.

5.10 Instrumentation

The instrumentation and procedure used to measure foam expansion, drainage time, and AFFF concentrations are described in Appendix A. Temperatures, wind speed, wind direction, foam solution flow, foam solution pressure and other test data (Appendix B) were recorded using a Data Acquisition system. Photographic recordings included two video cameras (equipped with time data generators), one recorder, and two 35mm cameras. A public address was set up on the main deck and in the control room where the video recording equipment was located. Comments made through the public address system were recorded on the video recording system.

6.0 RESULTS AND DISCUSSION

Three pretest fires and 33 fire tests were conducted in the test pen according to the schedule in Table 1. Data is recorded in Appendix C. The three pretest fires were necessary to correctly position the oscillating nozzle and to determine the appropriate test application rate. Identical application rates and a single nozzle were used in the 21 AFFF concentrate fire tests while four nozzles and similar but slightly different application rates were used in the 12 nozzles fire tests. Variable application rates were used in the nozzle testing since a single application rate was not common to each of the four nozzles.

Only four and one-half minutes of AFFF solution was applied to each of the AFFF concentrate fire tests. This was done to form an even baseline for

Sealability Test

Burnback Test

FIGURE 6.

FIRE PROTECTION AFTER EXTINGUISHMENT

comparing the effectiveness of the same quantities of different AFFF solutions. Tests were terminated after four and one-half minutes regardless of whether the flames were extinguished. Dry chemical extinguishers or a second foam nozzle were used to extinguish any remaining flames. The control and extinguishment times were found to be more rapid when using a manual operator than with the oscillating nozzle, therefore, only two and one-half minutes of AFFF solution was applied for each of the 12 nozzle tests.

All the AFFF concentrate tests were successful in bringing the test fires under control. Because the oscillating nozzle was positioned to project all the AFFF solution into the pen, certain areas of the pen such as the near corners did not have AFFF applied directly to it (Figure 5). In some tests due to a combination of swirling winds, wind shifts, and the resulting flow characteristics of the AFFF being used, the AFFF never flowed or pushed its way into corner areas to extinguish the flames completely. In these tests the remaining flames were extinguished after the conclusion of the standard foam application time. These remaining flames usually covered less than two percent of the test pen and took less than 15 seconds to extinguish. Detailed results of individual tests are listed and described in the following sections.

6.1 Environmental Factors

Wind was the only environmental factor which had an adverse effect on the fire test results. Wind effect was more pronounced on the AFFF evaluation testing than on the nozzle evaluations. Due to the preadjusted nozzle oscillations, computations for sudden wind shifts could not be accomplished during a test. Swirling winds or wind shifts created longer control and extinguishment times in some tests even though all foam was discharged into the test pen. During the nozzle evaluation, the manual operator attempted to attack the flames so that the wind was coming from behind him. This proved the ideal firefighting approach as the control and extinguishment times could be reduced by approximately 20 seconds when compared to extinguishing the fire when the wind was blowing directly at the firefighter.

6.2 Pretest Fires

The SFL nozzle on the oscillating base was used to conduct the three pretest fires. Each pretest fire involved 1,000 square feet (92.9m) and was conducted using 6% Military Specification AFFF. This was to be the baseline AFFF for comparison since it is the standard foam used on Coast Guard cutters. One pretest fire was conducted at an application rate of 0.04 gallons per square foot(1.6 lpmin/sqm). This rate neither controlled nor extinguished the fire after 12 minutes of AFFF application. The intensity of the flames appeared to consume the AFFF as it was applied by the oscillating nozzle. It was decided to try a second pretest using the same application rate but using a different application method. This second method involved applying the AFFF only to the front center portion of the pen to first build up a layer of AFFF in this area to establish control. It was thought that once control was established in this area the AFFF would then spread out to

extinguish the rest of the flames. This did not happen as planned. After six minutes of AFFF application only 50% of the flames were extinguished. The action of the AFFF as it was applied was being held in check by the flames. The two pretests showed that the AFFF when applied in a passive mode and at a low application rate was not sufficient to control or extinguish the fully involved fire. The flames easily consumed the smaller application rate of 0.04 gallon per square foot (1.6 lpmin/sqm). Therefore, it was decided to make a quantum jump to a 0.1 gallons per minute per square foot (4.07 lpmin/sqm) application rate. If this test application rate proved effective with the oscillating nozzle, it would also decrease the time required for control and extinguishment and reduce the fuel requirements needed for testing. This rate was selected for testing since as mentioned in Section 5.5 it has been used effectively in extinguishing fires. To serve our purpose, however, the extinguishment rate had to permit a long enough control time to differentiate between the effectiveness of the different AFFFs. Pretest fire number three was extinguished in three minutes and 18 seconds. This extinguishment time and application rate provided good data for comparison purposes.

6.3 Foam Quality

Foam quality is primarily a function of nozzle design. The same nozzle was used in evaluating all the AFFF concentrates so that differences inherent to a particular concentrate could be characterized. The foam quality produced by the four nozzles described in Section 3.5 was evaluated using the 3% Military Specification AFFF. This AFFF was selected for reasons mentioned in Section 6.3.2.

The foam quality results listed in Table 4 are based on the average of three observations for each nozzle used. The low expansion ratios and drainage times were expected as the nozzles used in the testing were designed primarily for water application. The twin agent nozzle designed for use with AFFF was the exception. As expected, it provided the highest expansion ratios and longest drainage times. Foam expansion in the 6-15 range and drainage times in the 3-8 minute range normally provide the greatest degree of fire protection after extinguishment.[6] Differences in drainage times or expansion ratios did not appear to affect flame extinguishing capabilities of the AFFF solution when discharged on the test fires. The greatest degree of fire protection after extinguishment however was found to be provided by AFFF concentrates having the highest expansion ratio and the longest drainage times.

The percent plus or minus deviation for the different foam quality columns in Table 4 were calculated by comparing the highest or lowest single deviation to the mean of the observations. One explanation for the consistent higher percentage proportioning rate is that the seawater used in the premix tank was drafted from over the side and could have contained a weak solution of foam from each prior test. This was because after each test the premix tank was drained and flushed several times over the test ship's side where it mixed with water in Mobile Bay which was then used in the next test.

TABLE 4
FOAM QUALITY RESULTS

AFFF CONCENTRATES

Nozzle Used	Operational Mode	No. Of Tests	AFFF Concentrate	Expansion Ratio ± 24%	25% Drainage Time ± 25%	Foam Proportioning ± 10%	Foam Application Time (Minutes)	Foam Depth (Inches)	Foam Depth (Centimeters)
SFL	Oscillating	3	1% Com. (Ansulite)	3.1	0.4	1.1	4 1/2	1/2 - 3/4	1.3 - 1.9
SFL	Oscillating	3	3% Mil.Spec. (Ansulite)	3.3	0.6	3.2	4 1/2	1 - 1 1/4	2.5 - 3.2
SFL	Oscillating	3	6% Mil.Spec. (Ansulite)	3.1	0.8	6.1	4 1/2	1 - 1 1/2	2.5 - 3.8
SFL	Oscillating	3	3% Com.(Light Water)	5.9	0.7	3.1	4 1/2	1 - 1 1/2	2.5 - 3.8
SFL	Oscillating	3	3% Pol.Sol. Resistant (Alcohol Type Concentrate)	4.1	1.4	3.2	4 1/2	1 - 1 1/2	2.5 - 3.8
SFL	Oscillating	3	3% Com.(Aer-O-Water)	5.8	0.7	3.1	4 1/2	1 1/2 - 2	3.8 - 5.1
SFL	Oscillating	3	3% Pol.Sol. Resistant (National Universal)	4.2	1.2	3.2	4 1/2	1 - 1 1/2	2.5 - 3.8
			NOZZLES						
CGAP	Manual	3	3% Mil.Spec. (Ansulite)	2.2	0.6	3.1	2 1/2	1/4	0.6
SFL	Manual	3	3% Mil.Spec. (Ansulite)	3.3	0.7	3.1	2 1/2	1/2	1.3
MFN	Manual	3	3% Mil.Spec. (Ansulite)	4.5	2.8	3.2	2 1/2	1/2 - 3/4	1.3 - 1.9
TAU	Manual	3	3% Mil.Spec. (Ansulite)	5.4	3.8	3.2	2 1/2	1/2 - 1	1.3 - 2.5

6.3.1 AFFF Concentrates

The AFFF concentrates and their expansion ratios are listed below in order of their decreasing values.

AFFF CONCENTRATES	EXPANSION RATIOS
3% Light Water, 3% Aer-O-Water	5.9, 5.8
3% National Universal, 3% Alcohol Type Concentrate	4.2, 4.1
6% Military Specification	3.4
3% Military Specification	3.3
1% Ansulite	3.1

This data shows that the commercial 3% AFFF concentrates and the 3% polar solvent resistant AFFF concentrates had larger expansion ratios than either the 3% or 6% Military Specification AFFF's or the 1% commercial AFFF concentrate. Military Specification AFFFs are not equivalent to the commercial or polar solvent resistant AFFFs in the degree of fire protection provided after flame extinguishment. Table 4 also shows that the 3% Military Specification AFFF concentrate and the 6% Military Specification AFFF concentrate are quite similar when comparing expansion ratios, thereby indicating a close degree of similarity in fire protection after extinguishment.

The AFFF concentrates are listed below in order of their decreasing drainage times:

AFFF CONCENTRATES	DRAINAGE TIMES (Minutes)
3% National Universal, 3% Alcohol Type Concentrate	1.2, 1.0
6% Military Specification	.8
3% Aer-O-Water, 3% Light Water	.7, .7
3% Military Specification	.6
1% Ansulite	.4

The data shows that the 3% polar solvent resistant AFFF's had the longest drainage times while the 1% commercial AFFF concentrate had the shortest drainage time. Drainage times were similar for the 3% commercial AFFF concentrates, and the 3% and 6% Military Specification AFFF concentrates. Thus the 3% and the 6% Military Specification AFFF concentrates are comparable regarding both drainage times and expansion numbers as previously indicated.

The foam depth measurements in Table 4 represent an average coverage of the different AFFF concentrates over the entire test pen surface.

The AFFF concentrates and their respective foam depths were averaged for three tests and are listed below in order of decreasing thickness:

AFFF CONCENTRATE	FOAM DEPTHS Inches	(Centimeters)
3% Aer-O-Water	1 1/2 - 2	(3.8 - 5.1)
3% Light Water	"	"
3% National Universal	"	"
3% Alcohol Type Concentrate	1 - 1 1/2	(2.5 - 3.8)
6% Military Specification	"	"
3% Military Specification	1 - 1 1/4	(2.5 - 3.2)
1% Ansulite	1/2 - 3/4	(1.3 - 1.9)

A 3% commercial AFFF concentrate had the thickest average foam depth while the 1% commercial AFFF concentrate had the thinnest overall foam depth. One 3% commercial AFFF, both polar solvent resistant AFFFs and the 6% Military Specification AFFF, were equal to each other and second in overall depths. The foam depth was slightly greater for the 6% Military Specification AFFF concentrate than for the 3% Military Specification AFFF concentrate.

6.3.2 Nozzles

The foam quality produced by the four different nozzles described in Section 3.5 was evaluated using the 3% Military Specification AFFF concentrate. This concentrate was selected for several reasons. Presently it conforms to Military Specification MIL-F-24385, is used by the Air Force, and is being evaluated by the Navy. If proven effective for the specific fire test scenario, it could be considered as an alternative for the 6% AFFF concentrate now being used on Coast Guard cutters.

The nozzles and their associated expansion ratios, drainage times, and average foam depths are listed below in their decreasing order:

NOZZLES	EXPANSION RATIO	DRAINAGE TIME	FOAM DEPTH Inches	(Centimeters)
TAU	5.4	3.8	1/2 - 1	(1.3 - 2.5)
MFN	4.5	2.8	1/2 - 3/4	(1.3 - 1.9)
SFL	3.3	.9	1/2	(1.3)
CGAP	2.2	.8	1/4	(0.6)

The data shows that the highest expansion ratio and drainage times were produced by the TAU nozzle while the CGAP nozzle produced the lowest expansion ratio and drainage times. The MFN produced the second best expansion ratio and drainage times, while the SFL nozzle was third in foam quality. The average foam depths produced by the nozzles decreases with the expansion ratios and drainage times.

6.4 Control/Extinguishment Times

The average control and extinguishment times for the fire tests are listed in Table 5. Each fire test covered 1000 square feet (92.9 sq m) and had a fully involved preburn of one minute. Fresh fuel was added to the test pen before each test. This assured the presence of lighter hydrocarbons for similar fire severity and decreased the time required for total flame involvement of the fuel surface. The fresh fuel insured the same degree of severity for conducting burnback and sealability tests.

The same application rate and nozzle (SFL) were used in the AFFF concentrate tests while different but similar application rates were used in the nozzle evaluations. A semi-straight stream pattern was used in all tests involving the SFL nozzle. This pattern insured that the application of the AFFF solution was confined to the test pen. The MFN was used in a straight-stream pattern due to its tube design construction. The CGAP nozzle was used in its fog pattern which in effect closely resembled a semi-straight stream. The TAU nozzle was used in a wide-angle fog pattern because of its fixed nozzle screen.

Individual control times for all fire tests are listed in Appendix C. Control times rather than extinguishment times provided a more accurate reflection of the capabilities of the AFFF concentrates because the oscillating attack pattern and wind shifts created difficulty in totally extinguishing all flames around the edges of the test pen. This is apparent when noticing that 11 of the 21 AFFF concentrate tests required a dry chemical extinguisher or second foam nozzle to extinguish flames in corners of the test pen where the AFFF concentrate did not reach.

The longer control times in the oscillating mode are a result of different extinguishing techniques (Figure 7). The oscillating mode used a passive methodical technique of extinguishment while the manual operator used a more aggressive technique. The oscillating nozzle was set at a preset angle and arc of oscillation which methodically covered as much of the entire test area as possible without wasting any AFFF outside the pen. Because of this pattern, certain corners and edges of the test pen did not receive AFFF directly over it and depended upon AFFF piling up and then spreading into these corners for extinguishment to occur. Even minor swirling winds inside the test parameters could shift the AFFF around the surface of the test pen and cause delays in flame extinguishment around the test pen corners.

Conversely, the manual operator with his aggressive technique produced the quickest control times despite a lower application rate. The nozzle operator was constantly on the offensive and used aggressive sweeping motions combined with a rapid advance toward the flames. This close approach to the flames was possible because the nozzle operator was fully dressed in a proximity suit. His support men on the hoseline behind him were also dressed in protective gear consisting of bunker coats, protective headgear, face shields, and gloves.

AFFF must be sprayed directly on the flames in order to achieve ideal extinguishing effectiveness. Piling the foam in one area of the test pen and waiting for it to spread out over the entire flaming surface was not totally effective or sufficient for extinguishment to occur in every test. In a fire

TABLE 5

CONTROL/EXTINGUISHMENT TIMES

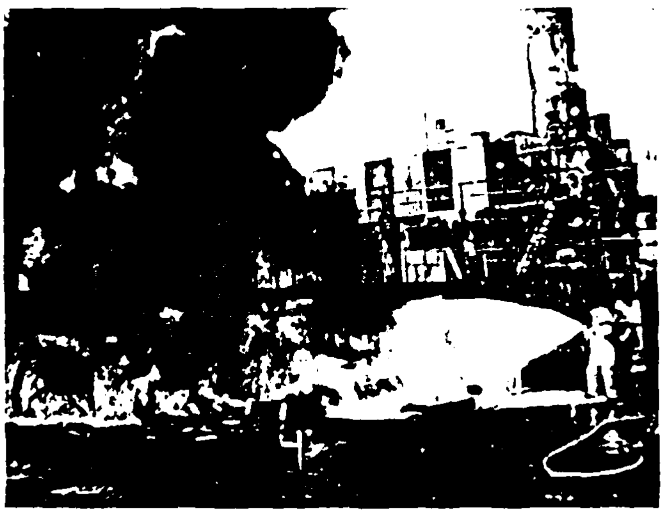
AFFF CONCENTRATES

AFFF Concentrate	Nozzle	Operational Mode	Number of Tests	AVERAGE Application Rate Flow (gpm)	AVERAGE Application Rate (gpm/sq.ft.)	AVERAGE Control Time Min/Sec ± 26%	Extinguishment Time Min/Sec
3% Aer-O-Water	SFL	Oscillating	3	95	0.095	1:31	Eleven of 21 tests required extinguishment of 5% surface area around inside test pen edges
3% Military Spec.	SFL	Oscillating	3	95	0.095	1:33	
3% Alcohol Type Concentrate	SFL	Oscillating	3	95	0.095	1:55	
3% National Universal	SFL	Oscillating	3	95	0.095	2:00	
1% Ansulite	SFL	Oscillating	3	95	0.095	2:01	
3% Light Water	SFL	Oscillating	3	95	0.095	2:12	
6% Military Spec.	SFL	Oscillating	3	95	0.095	2:22	

NOZZLES

						± 35	± 34
3% Military Spec.	MFN	Manual	3	60	0.06	0:48	1:07
3% Military Spec.	SFL	Manual	3	60	0.06	0:57	1:13
3% Military Spec.	CGAP	Manual	3	45	0.045	1:07	1:58
3% Military Spec.	TAU	Manual	3	50	0.05	1:08	1:52

Oscillating (passive)



Manual (aggressive)

FIGURE 7

NOZZLE CONTROL MODES USED

situation where it would be impossible for a vessel to maneuver to take advantage of the wind, a nozzle capable of projecting foam a reasonable distance would be required in order for the AFFF to reach and extinguish all of the flames. An example of this would be a fire on a vessel at a dock which would require the firefighting to take place regardless of the vessel's orientation to the wind.

The AFFF concentrates are listed in Table 5 according to increasing control times. The data shows all AFFF concentrates tested had quicker control times than the 6% Military Specification AFFF. Longer control times of the 6% Military Specification AFFF are partially attributed to the wind shifts occurring during its fire tests. The data also indicates, however, that the fire extinguishing capablity of AFFF solutions is not dependent upon higher concentrates to be effective, lower concentrates can be equally effective.

The nozzles are listed in Table 5 in order of decreasing effectiveness. Although the MFN and SFL nozzle exhibited the best overall control and extinguishment times, they did have a slightly higher test application rate than the two nozzles they outperformed. The difference in the application rate between the nozzles creates a question as to whether the higher application rate or the nozzle effectiveness caused the shorter control and extinguishment times. Although a 40% time difference existed between the nozzles with the shortest control times and the nozzles with the longest control times, this difference jumped to 76% when comparing extinguishment times. Although the rapid knockdown power of AFFF is well documented, it also appears that the key to its rapid effectiveness is its widespread deployment over the entire fire surface. Based upon this premise, the nozzles with the greatest application rate and the capability to reach out to a fire without scattering it would be the most effective. The longer extinguishment times of the CGAP nozzle and the TAU nozzle indicate that when using the same AFFF and similar application rates on the same fire size, that nozzle design is more important in the extinguishment phase than in the control phase.

Table 5 indicates the MFN and the SFL nozzle as having the best control and extinguishment times. These nozzles were tested in a straight stream pattern and the test results indicated both were effective in reaching a fire to control and extinguish it. The added foam thickness created by the MFN provided slightly greater control and extinguishment times by retaining better control of the areas it passed over. The MFN had only a straight stream pattern and in a close-up fire situation would require banking the foam off an obstruction. In this type of situation the risk occurs of splashing the fire in several directions occur due to the force of the straight stream. The SFL nozzle has the additional design capability over the MFN of projecting a fog pattern at a close-up fire without scattering it to endanger either the firefighter or the fire area.

The TAU nozzle and the CGAP nozzle were tested at application rates similar to the MFN and the SFL nozzle. A fog pattern was used with the TAU nozzle and the CGAP nozzle in order to achieve a similar application rate. The lack of reach attributed to the TAU nozzle and the CGAP nozzle is the principle reason for longer control and extinguishmnent times. The nozzle operator had to move his position several times in order to blanket the entire fire. The time required for this movement rather than the slightly lower

application rate is felt to be the reason for the longer control and extinguishment times. There is only a slight time difference required for control between the top two nozzles and between the other two nozzles in Table 5. This difference is greater when comparing extinguishment times.

A factor which could affect control and extinguishment times is an error in the proportioning rate. A premix foam tank was used to prepare the foam solution concentration to be used in each test. The actual test proportioning rate was checked by the two methods previously mentioned in Section 5.4. Small errors did show up in the actual test proportioning rates and were attributed to techniques used in filling the tank with AFFF or seawater and the use of the refractometers. The errors in the proportioning rates measurements were quite small and it is felt that the control and extinguishment times of the different AFFF concentrates were not affected.

6.5 Sealability

Each of the AFFF foams tested produced a foam blanket which was sufficient to keep the test fuel from reigniting around the hot metal pipe described in section 3.8 and the open flame source above it (Figure 6). Although each of the AFFF foam blankets blackened and bubbled around the hot metal piping during each test, open flames never broke out. This lack of flame breakout is attributed to the protection provided by the AFFF foam blanket as well as the fuel's overall low volatility. Figure 8 shows the temperatures recorded by a thermocouple attached to the surface of the piping used in the sealability testing. The highest temperatures indicated occur during the fire test when the thermocouple is exposed to the open flames during initial testing. As the flames are extinguished the temperatures drop immediately but then rise again when the propane burner is placed in the piping to conduct the sealability testing. Even though the hot metal piping was above the ignition temperature of the fuel during the sealability portion of the test the hot metal surface did not produce sufficient vapors from the low volatile test fuel for a flashback to occur. It is obvious, however, that some vapors were leaking through the foam blanket around the hot pipe because brief flashes of flames could sometimes be seen in that area. These flashes were always less than one second long. If the fuel source had been a more highly volatile fuel such as gasoline, it is questionable as to whether the AFFF concentrations would have kept the fuel from reigniting around the hot pipe surface since the AFFF foam blanket blackened around the pipe to a width of three inches (7.6 cm).

6.6 Burnback Resistance

Each of the curves in figure 9 and 10 represent the average of 8 to 12 data points recorded on the rate and time of fire enlargement during each burnback test. A curve fitting computer program was used to provide a smooth line curve in order to observe any major differences.

All of the AFFF's tested exhibited varing degrees of resistance in the burnback tests. Figure 9 shows that three of the 3% AFFF's produced a greater burnback resistance than the 6% Military Specification AFFF while two of the 3% AFFF's had a burnback resistance slightly less than that of the 6% Military Specification AFFF. The 1% AFFF produced the least effective burnback resistance. The test results indicated that a correlation existed

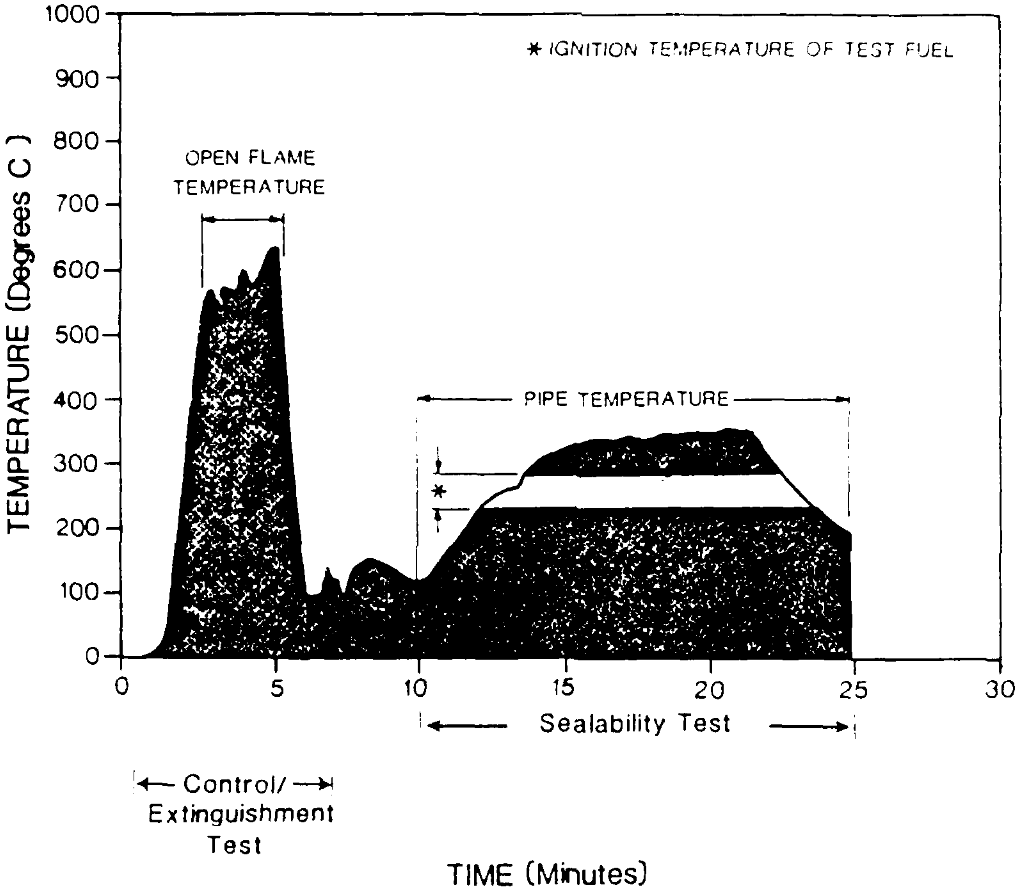


FIGURE 8

PIPE TEMPERATURES IN SEALABILITY TESTS

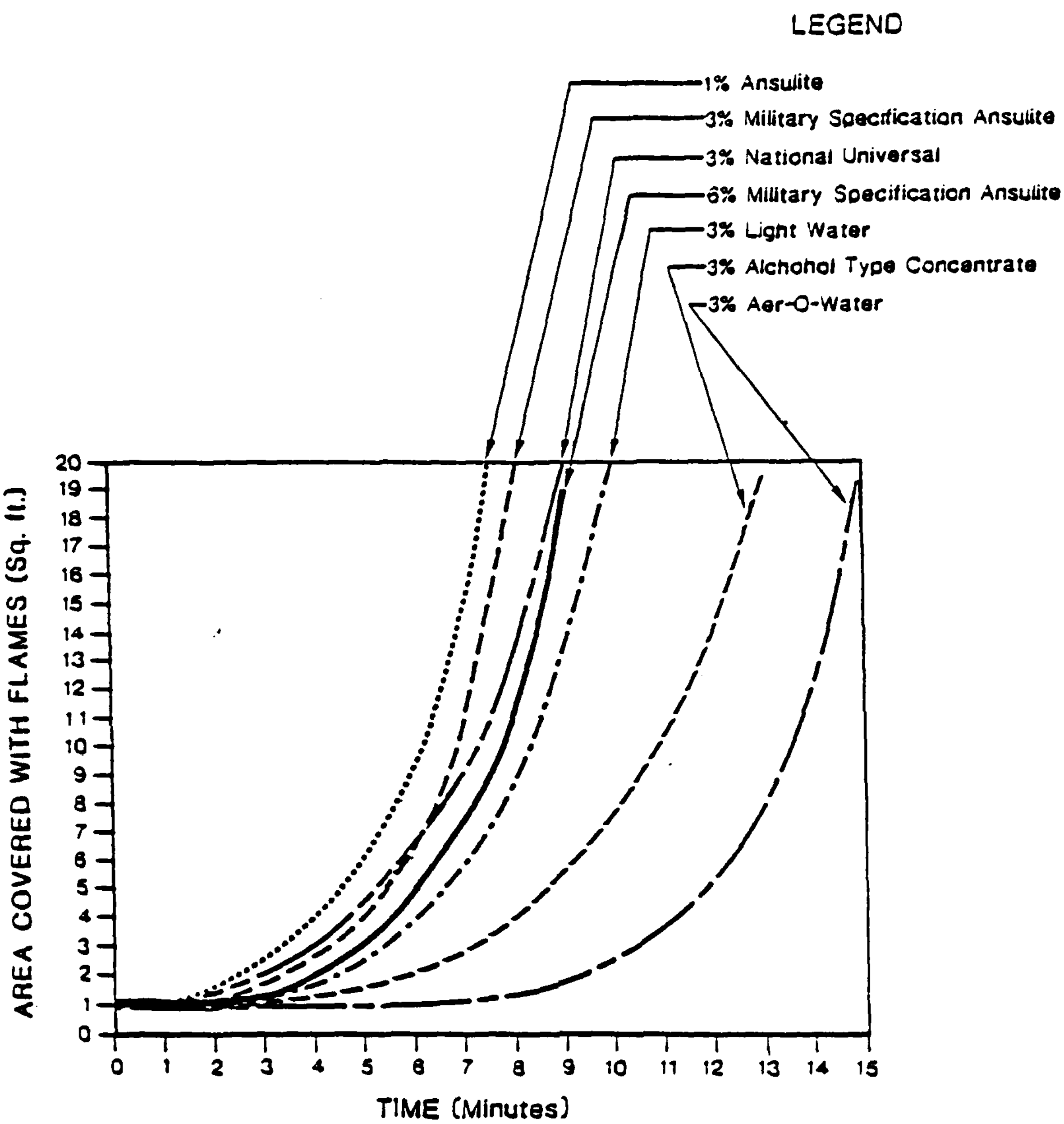


FIGURE 9
AFFF BURNBACK RESISTANCE

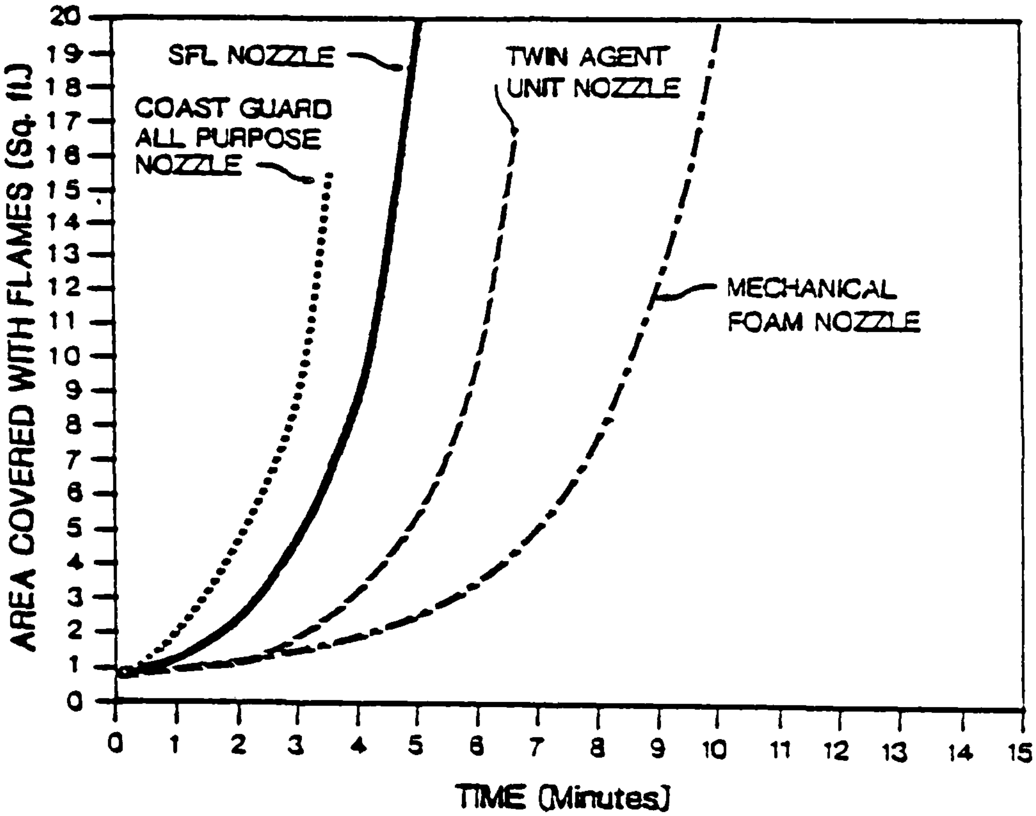


FIGURE 10
THE EFFECT OF NOZZLE DESIGN ON
BURNBACK RESISTANCE

between visible foam depth and resulting burnback resistance. The greater the visible foam depth, the greater the burnback resistance, while thinner foam blankets exhibited less burnback resistance. The AFFF's listed in table 5 with the greater foam depths show the longest burnback resistance (Figure 9), while the AFFF's with the thinnest foam depths exhibited the shortest burnback resistance. An example of this is that the 3% Aer-O-Water AFFF produced one of the thickest foam depths and also exhibited the longest burnback resistance. At the other end of the scale, the 1% Ansulite AFFF had the thinnest foam layer and the shortest burnback resistance.

The 4 nozzles tested produced foams with a range of different burnback resistance. The MFN produced foam with the best burnback resistance while the TAU nozzle was second. The SFL nozzle produced foam which was third in burnback resistance while the CGAP nozzle's foam was rated last. The test results indicate that the nozzles which produced the greatest foam depths (Table 5) also had the greatest burnback resistance (Figure 10).

7.0 SUMMARY/CONCLUSIONS

7.1 AFFF Concentrates

The test program showed that all the AFFF's tested (section 2.0) were as effective as or comparable to the 6% Military Specification AFFF in controlling and extinguishing deck spill fires involving a low volatile Class B fuel. The 3% Aer-O-Water AFFF and the 3% Military Specification AFFF exhibited the best overall control times while the 3% Light Water AFFF and the 6% Military Specification AFFF had the longest control times (i.e. poorer results). It is felt that the control times of the 3% light water AFFF and the 6% Military Specification AFFF were attributed to the shifting wind conditions which occurred during the testing of these AFFF's rather than to the characteristics of the agents themselves. The 3% National Universal AFFF, the 3% Alcohol Type Concentrate AFFF, and the 1% Ansulite AFFF exhibited similar control times which were between the AFFF's with the shortest control times and the AFFF's with the longest control times.

Each of the AFFF's tested exhibited a resistance to foam breakdown around the hot metal piping which was sufficient to prevent a reflash from occurring from the open flame source above the piping. The test results indicated that an AFFF's ability to resist breakdown around hot metal obstructions is closely linked to the depth of the foam around the hot obstruction. The AFFF's which produced the greatest foam depth also provided the greater resistance to blackening and edging away from the hot metal surfaces which in turn prevented the release of flammable vapors. AFFF's which produced thin foam layers exhibited less resistance to blackening of their edges and a greater recession from the hot metal piping. A reflash did not occur around the hot metal piping in any of the testing. It is felt that a reflash did not occur because of the fuel's low volatility and the action of the AFFF.

The 3% commercial AFFF's produced the most effective burnback resistance while the 3% polar solvent resistant AFFF's were second. The 3% and 6% Military Specification AFFF's were comparable and also third in ranking by burnback resistance. The 1% AFFF was the least effective of AFFF's in burnback resistance. A significant difference existed between the burnback resistance of the most effective 3% AFFF compared to that of the 6% Military

Specification AFFF. Only a minor difference existed between the burnback resistance of the least effective 3% AFFF when compared to the 6% military specification AFFF.

Test results demonstrate that 3% Military Specification AFFF could replace 6% Military Specification AFFF on Coast Guard cutters without a loss in fire fighting performance. The 3% Military Specification AFFF exhibited control times superior to those of the 6% Military Specification AFFF. It is felt, however, that the longer control times of the 6% Military Specification AFFF were attributed somewhat to swirling wind conditions occurring during the testing and not to foam characteristics. It was noted throughout the testing that slight shifts in wind directions occurring during a test could add 20 to 30 seconds to a control time effort. The 3% Military Specification AFFF did exhibit a slightly shorter burnback resistance than the 6% Military Specification AFFF but the difference, as noted in figure 9, is insignificant.

The conclusion that a 3% AFFF concentrate could replace the 6% Military Specification AFFF concentrate used on Coast Guard cutters was based on accurate foam proportioning. Test results indicate that the amount of AFFF concentrate in the foam solution plays an important part in making a fire resistant foam. This can be seen in Figure 9 which shows the 1% AFFF concentrate as being less effective in its burnback resistance compared to the other AFFF's. Because a premix tank was used in the testing, the proper AFFF proportioning was always maintained. No attempt was made to use or to test the accuracy of various AFFF proportioners used on Coast Guard cutters. This type of testing and sensivity testing of the firefighting performance to variations in proportioning should be considered if lower percentage AFFF concentrates are to be considered for use on Coast Guard cutters.

7.2 Nozzles

The four nozzles tested were effective in controlling and extinguishing the deck fires when using the 3% Military Specification AFFF. It was clearly demonstrated, however, that the effectiveness of a nozzle using AFFF for controlling and extinguishing deck fires is greatly increased when it is operated in a mode which can cover the entire fire area. This is evidenced by the shorter control and extinguishment times of the two nozzles (MFN and SFL) used in a straight stream mode when compared to the longer control and extinguishment times of the two nozzles (CGAP and TAU) which were operated in a fog pattern mode. In the fog pattern mode the operator had to reposition himself several times to attack the fire because the pattern could not cover the entire flame surface. Additional nozzle operator movements and lack of reach were responsible for the longer control and extinguishment times. This is demonstrated clearly by the increased time difference in the final extinguishment phase rather than the control phase (table 5) of the nozzle patterns in use. The quick knockdown characteristics of AFFF was quite evident but the test results also indicated that the AFFF must be spread rapidly across the entire flame surface to be utilized to its full effectiveness. This effectiveness will be reduced by tending to pile the AFFF in one area and waiting for it to flow across the flame surface.

The MFN and the SFL nozzle had the shortest control and extinguishment times while the CGAP nozzle and the TAU nozzle had the longest control and extinguishment times. The SFL nozzle with its multiple control modes

permitted it a greater flexibility which made it a more versatile and overall effective nozzle. Test results show the MFN produced a foam which had the longest burnback resistance, the second highest expansion ratio and the second longest drainage time. The twin-agent nozzle especially designed for AFFF fog usage gave as expected the highest expansion ratio and the longest drainage but it came in second in the burnback resistance. The foam this nozzle produced was blotchy in covering the test pan. Because of this the fuel surface was not covered by a visible foam and was quick to ignite. Although the SFL nozzle produced foam which was third in burnback resistance, expansion ratio and drainage times compared to the MFN or the TAU nozzle, it could function in both their modes and still be equally effective. The CGAP nozzle provided foam with the worse burnback resistance and the lowest expansion ratio and drainage time. It was the least effective of the nozzles.

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2. Fire Protection Systems, National Foam Engineering Manual, 1979.

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5. Commandant Instruction M16465.12, October 1978, Hazardous Chemical Data.

6. National Fire Codes, Standard for Evaluating Foam Fire Fighting Equipment on Aircraft Rescue and Fire Fighting Vehicles, NFPA No. 412, 1974.

7. McDaniel, Dale. Report of Deck Foam Fire Extinguishing Test Aboard M/V RHODE ISLAND. Department of Transportation and U.S. Coast Guard, June 1972.

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9. Geyer, George; Neri, Lawrence; Urban, Charles. Comparative Evaluation of Firefighting Foam Agents. Department of Transportation. Federal Aviation Administration. August 1979.

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Appendix A — Suggested Test Methods and Calculations

A-100. GENERAL

A-110. Purpose of Appendix

A-111. The following field tests for foam agent capabilities on aircraft rescue and fire fighting vehicles are given in order that standardization may be achieved in testing procedures.

A-112. The differences in the test equipment and the procedures followed to evaluate the characteristics of foams generated when using protein-type (including fluoroprotein) foam-liquid concentrates as distinct from the characteristics of foams generated when using aqueous-film-forming-foam (AFFF) concentrates should be noted and utilized accordingly.

A-120. Organization of Appendix

A-121. The test methods given are presented in the order of their mention in this Standard (see Article 400).

A-200. Ground Pattern and Foam Physical Property Tests

A-210. Turret Ground Pattern Test

A-211. Prior to the start of the tests the water tank shall be filled, the foam concentrate tank filled with the type of material to be used in actual emergencies (protein, fluoroprotein, or AFFF type), and the proportioner set for normal fire fighting operation. In order to standardize the results, the water and concentrate temperatures should lie within the 60-80° F range; if this is not possible, see A-500 in this Appendix for temperature correction factors when using protein-type foam liquid concentrates. (Similar correction factors have not been established when using AFFF type concentrates.)

A-212. These tests are designed to show the effective fire extinguishing patterns produced by foam falling on a ground spill and to determine the maximum range attainable by the turret stream under test. In order to establish a common condition for defining these patterns, the tests should be conducted under no-wind conditions, or as close to this condition as possible. The turret nozzle should be tilted upward to an angle of 30° with the horizontal. (This angle provides maximum reach for the pattern.) Foam shall be generated onto a paved surface for a period of exactly 30 seconds for each desired nozzle setting, such as straight-stream, dispersed or spray stream, and mid-stream. Immediately after foam discharge has stopped, markers shall be placed around the outside perimeter of the foam pattern as it fell on the ground. Fluid foams will tend to flow outward on standing and distort the original pattern. For purposes of defining the edge of the pattern any foam less than $\frac{1}{2}$ inch in depth should be disregarded and considered ineffective. After distances from the turret to the markers and distance between markers have been plotted on cross-section paper, the vertical axis should show the reach and the horizontal axis the pattern width for each nozzle setting. In the event that greater accuracy is desired, a grid of stakes on 3-ft. centers is preplaced over the area to be foamed. Foam depth measurements are made at each stake and then plotted on a scaled grid laid out on cross section paper. Points of equal depth are joined together in the manner of a contour map. This plot will indicate the uniformness of foam distribution from the nozzle. (See Figures in Article A-300 of this Appendix as typical pattern plots.)

A-220. Foam Sampling

A-221. The treatment of a foam after it has left the turret or nozzle has an important bearing on its physical properties. It is, therefore, extremely important that the foam samples taken for analysis represent as nearly as possible the foam reaching the burning surface in normal fire fighting procedure. Foam for analysis from a straight stream should be collected from the center of the ground pattern formed with the nozzle aimed for maximum reach. Similarly, for dispersed stream application foam should be sampled from the center of the resulting ground pattern area with the nozzle set for dispersed stream operation. In order to standardize and facilitate the collecting of foam samples, special collectors are used as shown in Figures 1A and B.

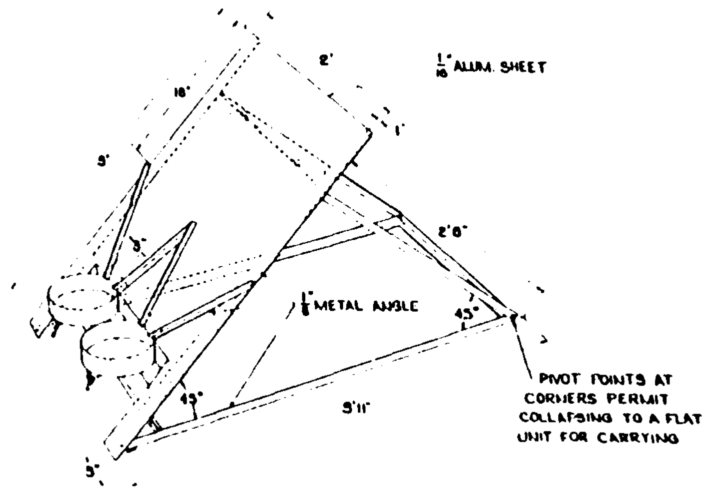

Figure 1A
Protein Foam Collector

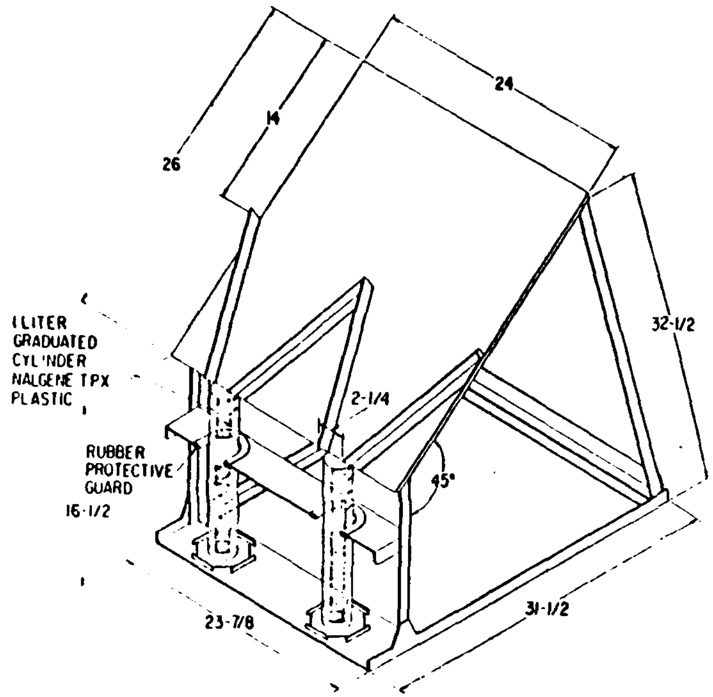

Figure 1B
Aqueous-Film-Forming-Foam Collector

A-222. The collector should be placed at the proper distance from the nozzle to be in the center of the pattern to be sampled. The nozzle should be placed in operation with the foam pattern off to one side of the collector until equilibrium is reached and then swung over onto the center of the backboard. When sufficient foam volume has accumulated to fill the sample containers (usually only a few seconds), a stop watch should be started to provide the zero time for the drainage tests described in Section A-240 and then the foam pattern should be directed off to one side again. *Immediately after the nozzle has been swung away from the board,* the sample container is removed, pans are removed, the top struck off with a straight edge, and all foam wiped off from the outside of the container. The sample is then ready for analysis.

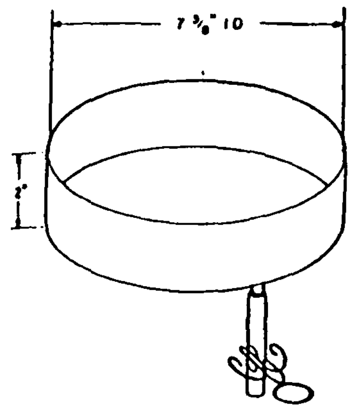

Figure 2. Protein Foam Container

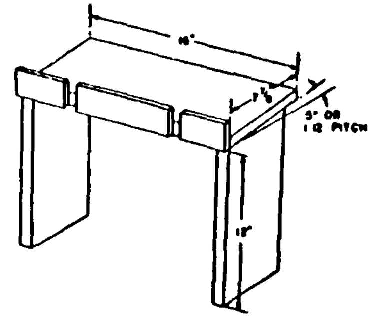

Figure 3. Protein Foam Container Stand

A-223. At the time the turret patterns are being established it will usually be convenient to obtain the foam samples for physical property tests. This may be done by swinging the turret off to one side to permit the pattern to fall on the foam sampling collector board as described above.

A-224. Different foam sample containers are used for collecting foams generated by protein-type foam-liquid concentrates (including the fluoroprotein type) as distinct from AFFF type concentrates (see Figures 1A and 1B).

a. **Collecting Foam Samples Generated by Protein-Type Foam-Liquid Concentrates.** The standard sample container is 2 inches deep and 7⅝ inches inside diameter (capacity of 1400 milliliters) preferably made of 1/16-inch-thick aluminum or plastic. In the bottom at the edge, a ¼-inch drain tube with a rubber tube and pinch cock is provided to draw off the foam solution as it accumulates. This device is shown in Figure 2.

b. **Collecting Foam Samples Generated by AFFF-Type Foam-Liquid Concentrates.** The standard container is a one-liter capacity graduated cylinder approximately 14 inches in height and 2½ inches in inside diameter. Either transparent plastic (polypropylene, Nalgene TPX) or glass cylinders may be used, however, the standard graduations on the plastic ones may be missing below 100 ml. and this is usually in the desired *working range.* For this reason 10 ml. graduation marks will probably have to be marked on the cylinders below 100 ml. In addition, each cylinder shall be cut off at the 1000 ml. mark to ensure a fixed volume of foam as a sample (see Figure 1B).

A-230. Foam Expansion Determination

A-231. The following apparatus is used in determining foam expansion data. (The type foam collector and sample container will depend on whether protein or AFFF-type concentrates are used (see A-224).

a. 2 — sample containers

b. 1 — foam collector board

c. 1 — scale or balance, 1000 gram capacity, weighing to nearest gram.

d. 2 — work sheet forms (see Appendix B)

A-232. Protein foam samples obtained in the sample pan as described in A-224(a) should be weighed to the nearest gram. The expansion of the foam is calculated by the following equation:

$$\text{Expansion} = \frac{1400\text{ ml.}}{\text{full wt. minus empty weight (grams)}}$$

A-233. AFFF foam samples obtained in the graduates as described in A-224(b) should be weighed to the nearest gram. The expansion of the foam sample is calculated by the following equation:

$$\text{Expansion} = \frac{1000\text{ ml.}}{\text{full wt. minus empty weight (grams)}}$$

A-240. Foam Drainage Time Determination

A-241. The rate at which the liquid drops out from the foam mass is called the "drainage rate" and this rate is a direct indication of degree of stability and the viscosity of a foam. A single value used to express the relative drainage rates of different foams is the "25 per cent Drainage Time"; this is the time in minutes that it takes for 25 per cent of the total liquid contained in the foam in the sample containers to drain out. This test is performed on the same sample as used in the expansion determination. Dividing the net weight of the foam sample by four will give the 25 per cent volume in milliliters of liquid contained in the foam.

A-242. The following apparatus is used in determining the foam's drainage time:

a. 1 — stop watch

b. 2 — 100 *milliliter graduates (for protein-type foams)*

c. 1 — sample stand (for protein-type foams)

d. 2 — one liter graduates, shortened (for AFFF-type foams)

e. 2 — work sheet forms (Appendix B)

A-243. **Protein-Type Foams.** The protein foam sample container should be placed on a stand as shown in Figure 3 and at regular suitable intervals the accumulated solution in the bottom of the pan is drawn off into a graduate. The time intervals at which the accumulated solution is drawn off are dependent on the foam expansion. For foams of expansion 4 to 10, one-minute intervals should be used; for foams of expansion 10 and above, two-minute intervals should be used because of the slower drainage rate of foams in this category. In this way a time-drainage volume curve is obtained and after the 25 per cent volume has been exceeded, the 25 per cent drainage time is interpolated from the data.

A-244. **AFFF-Type Foams.** In order to find the time for the 25 per cent volume to drain out, the AFFF type foam sample container should be placed on a level surface at a convenient height and at one-minute time intervals the level of accumulated solution in the bottom of the cylinder should be noted and recorded on the work sheet. The interface between the liquid on the bottom and the foam above is easily discernible and easy to read. In this way a time-drainage volume relationship is obtained and after the 25 per cent volume has been exceeded, the 25 per cent drainage time is interpolated from the data.

A-245. ***Sample Calculation — Protein-Type Foams.*** A sample calculation of expansion and drainage time, using protein foam as an example is as follows:

The net weight of the foam sample in the pan has been found to be 200 grams. Since one gram of foam solution occupies a volume of essentially one milliliter (ml.) the total volume of foam solution contained in the given sample is 200 ml.

$$\text{Expansion} = \frac{\text{volume of foam}}{\text{volume of solution}} = \frac{1400\text{ ml.}}{200\text{ ml.}} = 7$$

$$25\%\text{ Volume} = 0.25\text{ total volume of solution} =$$

$$\frac{\text{Volume of solution}}{4} = \frac{200\text{ ml.}}{4} = 50\text{ ml.}$$

Then if the time-solution volume data has been recorded as follows:

Time Min.	Drained Solution Volume Ml.
0	0
1.0	20
2.0	40
3.0	60

It is seen that the 25 per cent volume of 50 ml. lies within the 2 to 3 minute period. The increment to be added to the lower value of 2 minutes is found by interpolation of the data:

$$\frac{50\text{ ml. (25\% Volume)} - 40\text{ ml. (2 min. Volume)}}{60\text{ ml. (3 min. Volume)} - 40\text{ ml. (2 min. Volume)}} = \frac{10}{20} = 0.5$$

Therefore, the 25 per cent drainage time is found by adding 2.0 min. + 0.5 min. and gives a final value of 2.5 min.

A-246. In the handling of unstable foams it must be remembered that they lose their liquid rapidly and the expansion determination must be carried out with speed and dispatch in order not to miss the 25 per cent drainage volume. It may even be necessary to defer the expansion weighing until after the drainage curve data has been recorded. The stop watch is started at the time the foam container is filled and continues to run during the time the sample is being weighed.

A-250. Concentration Determination

A-251. This test is made to determine the percentage of foam concentrate (protein type or AFFF type) solution being supplied to the foam makers. The test is based on using a hand refractometer to measure the refractive index of the solution which varies proportionally to the concentration.

A-252. The first step in this procedure is to prepare a calibration curve for the intended use. This has been found necessary because the source of water and brand or mixture of foam concentrate will affect the results. Using water from the tank and foam concentrate from the tank, standard solutions of 3, 6, and 9 per cent are made up by pipetting 3, 6, and 9 milliliters of foam concentrate respectively into three 100 milliliter graduates and then filling to 100 milliliter mark with the water. After thoroughly mixing, a refractive index reading is taken of each standard. This is done by placing a few drops of the solution on the refractometer prism with a medicine dropper, closing the cover plate and observing the scale reading at the dark field intersection. (See Figures 4, 5, and 6.) A plot is made on graph paper of scale reading against the known foam solution concentrations and serves as a calibration curve for this particular foam test series. Portions of solution drained out during the previously described drainage rate test are conveniently used as a source of sample for the refractometer in analysis. Refractive readings of the unknown are referred to the calibration curve and the corresponding foam solution concentration read off.

NOTE: *All refractometer measurements should be conducted at the calibration temperature or appropriate temperature correction factors applied.*

A-253. Apparatus Needed

a. 3 — 100 milliliter graduates
b. 1 — measuring pipette (10 milliliter capacity)
c. 1 — 100 milliliter beaker
d. 1 — 500 milliliter beaker
e. 1-Hand Refractometer (American Optical Co. Model 10430 or equivalent.) There are numerous refractometers of this general type available. The scale markings may vary but this is not important because the user must make his own calibration.

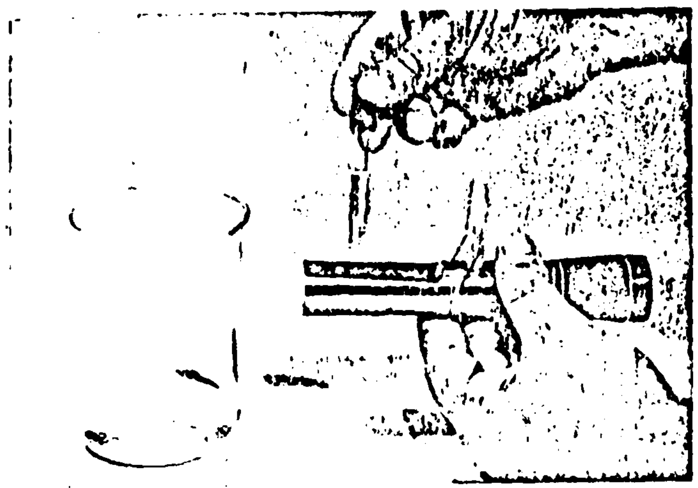

Figure 4. The index of refraction is measured by placing a few drops of the solution to be tested on the prism of a refractometer and closing the cover plate. This is a typical refractometer suitable for this purpose.

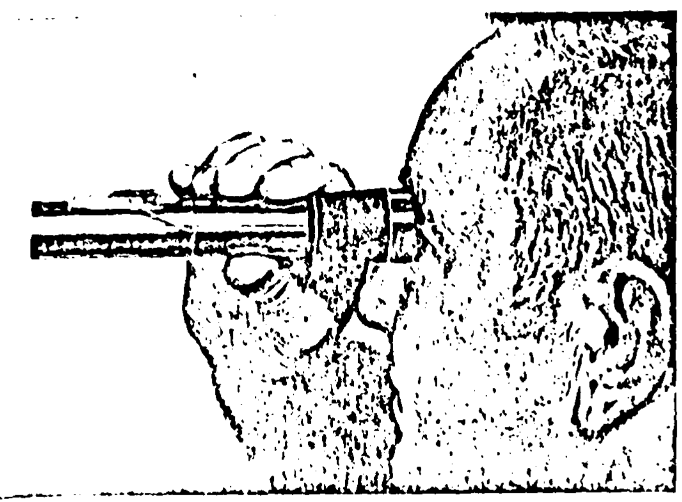

Figure 5. When this type refractometer is held up to a light source a reading is taken where the dark field intersects the numbered scale.

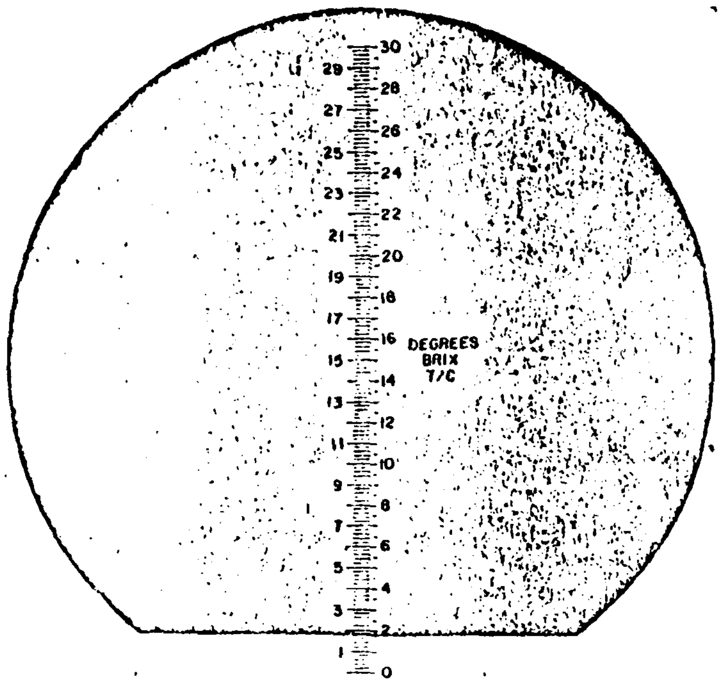

Figure 6. This illustrates the field of view looking into the refractometer illustrated in Figures 4 and 5 containing a 6 per cent AFFF Solution. The dark field intersects the scale at 1.7 and this value is recorded as the reading for a 6 per cent concentration.

A-260. Hand Line Test

A-261. The hand line foam nozzle, operating at its recommended pressure, shall discharge foam onto a paved surface for the purpose of determining the output pattern. The nozzle should be held at its normal working height and tilted upward to form a 30-degree angle with the horizontal. Markers shall be set out to denote the outline of the effective foam pattern and plotted, as described under the turret test above. The resultant patterns from both the straight stream nozzle setting and the fully dispersed nozzle setting should be established.

a. Auxiliary nozzles such as bumper and undertruck nozzles (if any) should be operated, elevated for maximum range (if applicable), to establish their protective patterns. If variation is to be expected in nozzle performance due only to partial component operation, this condition should be reproduced and tested.

A-262. At the time the handline nozzle patterns are being taken it will usually be convenient to obtain the foam samples for the physical property tests. This may be done by swinging the nozzle off to one side to permit the foam to fall on the foam collector board described in Section A-210.

A-263. The foam samples are to be analyzed as outlined in Section A-230, 240, and 250.

A-300. FOAM PATTERN TESTS

A-310. Typical Turret Pattern Plot

A-311. Figures 7A, 7B, 7C and 7D show typical plots of the ground patterns of the foam discharge of a turret nozzle which may be used as a model for reporting these and similar patterns. *Figure 7E shows how* stakes are laid out for measuring the pattern, Figure 7F illustrates a foam turret application, and Figure 7G how measurements are made.

APPENDIX B
INSTRUMENTATION
Title: AFFF Deck Fires

Channel Number	Instrument Description	Location	Output Range In Engineering units
0	Thermocouple, Type K inconel - sheathed	Fwd test coaming, 10 ft from Stbd test coaming	0-538°F (0-1000°C)
1	Thermocouple, Type K inconel - sheathed	Fwd test coaming, 10 ft from Port test coaming	0-538°F (0-1000°C)
2	Thermocouple, Type K inconel - sheathed	Port test coaming, 10 ft from Fwd coaming	0-538°F (0-1000°C)
3	Thermocouple, Type K inconel - sheathed	Port test coaming, 10 ft from Aft coaming	0-538°F (0-1000°C)
4	Thermocouple, Type K inconel - sheathed	Aft test coaming, 10 ft from Port test coaming	0-538°F (0-1000°C)
5	Thermocouple, Type K inconel - sheathed	Aft test coaming, 10 ft from Stbd test coaming	0-538°F (0-1000°C)
6	Thermocouple, Type K inconel - sheathed	Stbd test coaming, 10 ft from Aft test coaming	0-538°F (0-1000°C)
7	Thermocouple, Type K inconel - sheathed	Stbd test coaming, 10 ft from Fwd test coaming	0-538°F (0-1000°C)
8	Thermocouple, Type K inconel - sheathed	Reignition source, corner pipe (Aft-Stbd)	0-538°F (0-1000°C)
9	Thermocouple, Type K inconel - sheathed	Reignition source, pipe burner (flame)	0-538°F (0-1000°C)
10	Thermocouple, Type K inconel - sheathed	Water in test pen	0-538°F (0-1000°C)
11	Thermocouple, Type K quick tip	Foam solution in tank	0-538°F (0-1000°C)
12	Wind Direction	02 deck, FWD	0-360°T
13	Anemometer	02 deck, mid-ship	0-50 mph
14	Barometer	Trailer	27-31.5 in. of Hg
15	Fire Main Pressure	At nozzle	0-120 psi (0-827 kN/m^2)
16	Foam Solution Flow	At nozzle	0-150 gpm (568 lpm)
17	Ambient temperature	Outside trailer	0-538°F (0-1000°C)
18	Calorimeter	Aft of test pen	0-15 Btu/sq ft/sec (0-145 kW/sq m/sec)
19	Radiometer	Aft of test pen	0-5 Btu/sq ft/sec (0-51 kW/sq m/sec)
20	Humidity	Outside trailer	0-100% R.H.

APPENDIX C
AFFF FIRE TEST DATA

Test#	AFFF Concentrate	Test Date	Nozzle	Operational Mode	Flow Rate gpm	Application Rate	Control Time (min/sec)	Extinguishment Time / 2nd method used (min/sec)	Wind Conditions	Average Foam Depth (inches)	Foam Application Time (min)
Pt#1	6% Mil Spec.	1-12-83	SFL	Oscillating	40	.04	NONE	12:05/no fuel left	Poor		
#2	6% Mil Spec.	1-16-83	SFL	Oscillating	40	.04	7:15	8:10	Good		
#3	6% Mil Spec.	1-16-83	SFL	Oscillating	95	.1	1:20	3:18	Good		
T#1	6% Mil Spec.	1-16-83	SFL	Oscillating	95	.1	2:45	7:20/Dry Chem	Good/Poor	1 - 1 1/2	4 1/2
2	3%Aer-O-Water	1-17-83	SFL	Oscillating	95	.1	1:20	3:30	Good	1 1/2 - 2	4 1/2
3	3% Mil Spec.	1-17-83	SFL	Oscillating	95	.1	1:25	3:10	Good	3/4 - 1	4 1/2
4	3% Mil Spec.	1-22-83	SFL	Oscillating	95	.1	1:35	5:21/Dry Chem	Good	3/4 - 1	4 1/2
5	6% Mil Spec.	1-22-83	SFL	Oscillating	95	.1	2:40	5:05/Dry Chem	Neutral	1 - 1 1/2	4 1/2
6	3%Aer-O-Water	1-22-83	SFL	Oscillating	95	.1	1:38	3:45	Neutral	1 1/2 - 2	4 1/2
7	3%aer-O-Water	1-24-83	SFL	Oscillating	95	.1	1:34	5:45/Dry Chem	Good	1 1/2 - 2	4 1/2
8	3% Mil Spec.	1-24-83	SFL	Oscillating	95	.1	1:39	5:35/Dry Chem	Good	3/4 - 1	4 1/2
9	6% Mil Spec.	1-25-83	SFL	Oscillating	95	.1	2:10	5:10/2nd foam nozzle	Poor	1 - 1 1/2	4 1/2
10	3% National Universal	1-25-83	SFL	Oscillating	95	.1	1:55	5:05/Dry Chem	Poor	1 - 1 1/2	4 1/2
11	3% Light Water	1-25-83	SFL	Oscillating	95	.1	2:30	5:05/2nd foam nozzle	Neutral/ Poor	1 1/2 - 2	4 1/2
12	1% Ansulite	1-25-83	SFL	Oscillating	95	.1	2:32	5:10/2nd foam nozzle	Good	3/4	4 1/2
13	1% Ansulite	1-25-83	SFL	Oscillating	95	.1	2:00	4:56/2nd foam nozzle	Good	3/4	4 1/2
14	3% National Universal	1-28-83	SFL	Oscillating	95	.1	2:15	5:15	Good	1 - 1 1/2	4 1/2
15	3% Light Water	1-28-83	SFL	Oscillating	95	.1	1:45	4:00	Good	1 1/2 - 2	4 1/2
16	3% Light water	1-28-83	SFL	Oscillating	95	.1	2:20	3:55	Poor	1 1/2 - 2	4 1/2
17	1% Ansulite	1-28-83	SFL	Oscillating	95	.1	1:31	4:50	Poor	3/4	4 1/2
18	3% National Universal	1-31-83	SFL	Oscillating	95	.1	1:50	5:02/2nd foam nozzle	Good	1 - 1 1/2	4 1/2
19	3% Alcohol Type Concentrate	1-28-83	SFL	Oscillating	95	.1	2:05	5:15	Neutral	1 - 1 1/2	4 1/2
20	3% Alcohol Type Concentrate	1-31-83	SFL	Oscillating	95	.1	2:10	4:00	Good	1 - 1 1/2	4 1/2
21	3% Alcohol Type Concentrate	1-31-83	SFL	Oscillating	95	.1	1:31	3:30	Good	1 - 1 1/2	1 1/2
22	3% Mil Spec.	1-31-83	TAU	Manual	50	.05	:55	1:35	Good	3/4	2 1/2
23	3% Mil Spec.	1-31-83	SFL	Manual	60	.06	1:00	1:10	Good	3/4	2 1/2
24	3% Mil Spec.	2-4-83	MFN	Manual	60	.06	:45	:56	Good	3/4	2 1/2
25	3% Mil Spec.	2-4-83	CGAP	Manual	45	.05	1:00	1:45	Good	1/2	2 1/2
26	3% Mil Spec.	2-7-83	TAU	Manual	50	.05	1:00	1:45	Poor	3/4	2 1/2
27	3% Mil Spec.	2-8-83	SFL	Manual	60	.06	:45	1:00	Good	3/4	2 1/2
28	3% Mil Spec.	2-8-83	MFN	Manual	60	.06	:46	1:02	Good	3/4	2 1/2
29	3% Mil Spec.	2-8-83	CGAP	Manual	45	.05	:55	1:35	Good	1/2	2 1/2
30	3% Mil Spec.	2-9-83	TAU	Manual	50	.05	1:30	2:15	Neutral	3/4	2 1/2
31	3% Mil Spec.	2-9-83	SFL	Manual	60	.06	1:05	1:30	Poor	3/4	2 1/2
32	3% Mil Spec.	2-9-83	MFN	Manual	60	.06	:53	1:25	Poor	3/4	2 1/2
33	3% Mil Spec.	2-9-83	CGAP	Manual	45	.05	1:25	2:35	Neutral-Poor	1/2	2 1/2